PB90-127473

Immobilization Technology Seminar: Speaker Slide Copies and Supporting Information

(U.S.) Environmental Protection Agency, Cincinnati, OH

Oct 89

U.S. Department of Commerce
National Technical Information Service
NTIS

BIBLIOGRAPHIC INFORMATION

PB90-127473

Report Nos: CERI-89-222

Title: Immobilization Technology Seminar: Speaker Slide Copies and Supporting Information.

Date: Oct 89

Authors: C. Wiles, and E. Barth.

Performing Organization: Environmental Protection Agency, Cincinnati, OH. Center for Environmental Research Information.

Supplementary Notes: Also available from Supt. of Docs.

NTIS Field/Group Codes: 68C

Price: PC A09/MF A01

Availability: Available from the National Technical Information Service,
Springfield, VA. 22161

Number of Pages: 183p

Keywords: *Meetings, *Solidification, *Stabilization, *Waste treatment, *Hazardous materials, *Vitrification, Site surveys, United States, Performance evaluation, Field tests, Quality assurance, Chemical tests, Physical tests, *Technology utilization, Slides(Projectors), Pollution regulations, Waste management, Resource Conservation and Recovery Act, Superfund program, Best technology, Remedial action.

Abstract: Solidification/stabilization technology is being utilized as a treatment technology for Resource Conservation and Recovery Act RCRA listed waste and waste from uncontrolled hazardous waste sites. Several Best Demonstrated Available Technology (BDAT) levels for Resource Conservation and Recovery Act (RCRA) waste codes are based on solidification/stabilization technology. Vitrification technology is emerging as an alternative technology for hazardous waste. Approximately 25 percent of the Records of Decision (RODs) for Fiscal Year 1988 for the Superfund Program involved solidification/stabilization.

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Technology Transfer

October 1989

CERI-89-222

EPA

PB90-127473

Immobilization Technology Seminar

Speaker Slide Copies and Supporting Information

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SPRINGFIELD, VA. 22161

IMMOBILIZATION TECHNOLOGY SEMINAR

Speaker Slide Copies and Supporting Information

October 1989

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IMMOBILIZATION PROCESSES

OVERVIEW

SECTION 1

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IMMOBILIZATION PROCESSES OVERVIEW

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Solidification/stabilization technology is being utilized as a treatment technology for Resource Conservation and Recovery Act RCRA listed waste and waste from uncontrolled hazardous waste sites. Several Best Demonstrated Available Technology (BDAT) levels for Resource Conservation and Recovery Act (RCRA) waste codes are based on solidification/stabilization technology. Vitrification technology is emerging as an alternative technology for hazardous waste. Approximately 25 percent of the Records of Decision (RODs) for Fiscal Year 1988 for the Superfund Program involved solidification/stabilization.

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Barth, E.F., Wiles, C., Technical and Regulatory Status of Solidification/Stabilization in the United States. Proceedings on the Application of U.S. Control Technology in Korea, Seoul, Korea (1989).

U.S. EPA Guide to the Disposal of Chemically Stabilized and Solidified Waste, SW-872 (September, 1980)

U.S. EPA Handbook for Stabilization/Solidification of Hazardous Waste, EPA 540/2-86/001 (June, 1986).

TECHNICAL AND REGULATORY STATUS OF SOLIDIFICATION/STABILIZATION IN THE UNITED STATES

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1.0 INTRODUCTION

Solidification/stabilization (S/S) technology has been used for over 20 years to treat U.S. industrial waste and more recently for contaminated soils and municipal waste combustion residuals.

1.1 SOLIDIFICATION/STABILIZATION TECHNOLOGY

1.1.1 Definitions

Definitions for S/S technology vary depending upon the source. Other terms that have been used are immobilization and fixation. In very general terms, S/S, as it relates to managing hazardous waste, refers to a technology where one uses additives or processes to transform the waste into a more manageable form or less toxic form by physically and/or chemically immobilizing the waste constituents. It is important to understand the terminology being used in order to properly evaluate the technology for potential application.

1.1.2 Objectives

The broad objective of S/S technology is to contain a waste contaminant and prevent or minimize the release of the contaminant into the environment. In practice this broad objective may be realized by several mechanisms which include producing a solid; improving the handling characteristics of the waste; decreasing the surface area across which the transport of the contaminant may occur; and limiting the mobility of the contaminant when exposed to leaching fluids. The ideal objective is to chemically transform or bond the toxic contaminant into a non-toxic form. Realistically, chemical bonding of the binder to the contaminant does not routinely occur with available state-of-the-art inorganic S/S technologies. More vendors, however, are claiming that chemical bonding from additive reagents does take place, rather than or in addition to microencapsulation.

1.1.3 Binders and Binding Mechanisms

Binder systems can be placed into two broad categories, inorganic or organic. Most inorganic binding systems in use include varying combinations of hydraulic cements, lime, pozzolans, gypsum, and silicates. Organic binders used or experimented with include epoxy, polyesters, asphalt/bitumen, polyolefins (primarily polyethylene and polybutadiene), and urea formaldehyde. Combinations of inorganic and organic binder systems have been used. These include diatomaceous earth with cement and polystyrene; polyurethane and cement, polymer gels with silicate and lime cement and organic modified clays.

1.1.4 Process Types

S/S process types normally found in the U.S. are: in-drum processing, in-plant processing, mobile plant processing, and in-situ processing. Combinations of these process types may be used depending upon specific requirements at a given site. In the case of a contaminated soil area, in-situ and mobile type of processes are most often used.

1.2 Current Status of S/S in the U.S.

Although S/S has seen significant use for treating industrial waste in the U.S., there are technical and regulatory factors which may greatly affect its future use. U.S. EPA regulations and proposed regulations controlling the treatment and disposal of hazardous waste and contaminated soil and debris will be the major factor determining how much S/S technology will be used. The remaining portions of this paper will further discuss the U.S. EPA S/S programs and the factors important in determining how much S/S will be used in the future in the U.S.

2.0 THE U.S. EPA PROGRAM IN SOLIDIFICATION/STABILIZATION

The U.S. EPA programs in S/S include evaluating S/S as a best demonstrated available technology for treating hazardous waste, evaluating S/S for treating contaminated soil and debris, as well as municipal waste combustion residuals and conducting research to develop a more comprehensive scientific understanding of the technology.

2.1 RESEARCH

The current U.S. EPA research (Table I) has emphasized investigating interferences to S/S, investigating waste-binder interaction and waste disposition sites, and study of methods for predicting performance of S/S products.

2.1.1 Interfering Agents

Research on interfering agents will produce data on the effects that interfering inorganics (certain metals, sulfates, etc.) and organics (oil, grease, HCB, TCE, phenol, etc.) may have on generally used pozzolanic binder systems. The information will be useful in evaluating applications for delisting hazardous waste and for permits to treat hazardous wastes with S/S, particularly for those waste streams contaminated with organics. This information and that from research on factors critical to S/S will also aid decisions on potential waste pretreatment techniques for enhancing S/S performance. Data from physical and chemical tests are being analyzed to determine if a correlation exists between physical properties of the solidified waste form and its ability to resist stresses when exposed to leaching situations. An extensive literature search on interference compounds and interference testing has been completed (2,3).

2.1.2 Evaluating Test Methods

An effort with Environmental Canada is emphasizing evaluation of several leaching tests for determining the extent of toxic constituent binding. Protocols for examining physical properties are also being evaluated. This research includes actual waste and synthetic sludges solidified by vendors. Information on the performance of several different solidified products can be compared. This research will provide important data to compare current U.S. EPA regulatory leaching procedures with others beign tested. However, more research is needed to determine the long-term effectiveness of this treatment technology.

2.1.3 Morphological Studies

Electron scanning and x-ray diffraction microscopy techniques and solvent extractions are being used to investigate waste/binder interactions. The objective is to better understand S/S by identifying binder reaction phases where the waste from other research projects are being examined in efforts to correlate results of physical and chemical tests with performance of S/S products. Results from these specific studies have indicated that physical entrapment of inorganic metals is a predominant containment mechanism (4). However, some results are also indicating formation of altered or new crystal structures in some phases which appear to be chemically bonding some organics. Indications are that this type research could provide information useful in preparing binder formulations better able to treat a specific waste.

2.1.4 Air Emissions

Because of the nature of many solidification processes, uncontrolled air emissions are a potential problem to workers and the environment. Investigations are being conducted to determine the magnitude of these air emissions (5, 6). Processes being evaluated are Portland cement - fly ash and lime kiln dust - fly ash mixtures. As expected, mixing causes the greatest air emissions. Some additives such as lime result in exothermic reactions which increases the release of volatile compounds or may cause combustion. Capture and treatment of these emissions may be required to protect worker health and the environment, particularly in cases where the waste or contaminated soils contain volatile compounds.

2.2 EVALUATION OF S/S AS AN AVAILABLE TREATMENT TECHNOLOGY

2.2.1 Treatment of Hazardous Wastes

In the United States, the Hazardous and Solid Waste Amendments (HSWA), which amended the Resource Conservation and Recovery Act (RCRA) provide detailed procedures dictating how hazardous waste is defined, controlled, and managed. Wastes classified as hazardous under RCRA are often referred to as RCRA hazardous waste. Key provisions of HSWA are the ones which ban the land disposal of hazardous waste unless it is proven to be more protective of the environment and human health than other alternatives. The legislation requires that all hazardous waste be treated by the best demonstrated available treatment (BDAT) instead of and prior to land disposal. The U.S. EPA is required to determine and specify levels to which BDAT technologies can treat RCRA waste. S/S is one of several BDAT technologies being evaluated for non-waste waters (see Table II). In this program selected hazardous wastes are solidified/stabilized by portland cement, lime kiln dust, and lime/fly ash mixtures. Various ratios of waste to binder for each binder system is then evaluated by the Unconfined Compressive Strength Test (UCS) after a cure time of 7, 14, 21 and 28 days. Cured samples are then subjected to the U.S. EPA's Toxicity Characteristics Leaching Procedure (TCLP) extraction test. Leachate from the TCLP is analyzed for the pollutants of concern, to determine how effective S/S can be for treating the selected hazardous waste. Results will be important in determining how much S/S will be used to treat hazardous waste in the U.S.

2.2.2 Treatment of Contaminated Soils

The remediation of contaminated soils from uncontrolled dump sites, is controlled under legislation referred to as the Superfund Amendments and Reauthorization Act (SARA) which amended the Comprehensive Environmental Reclamation Compensation Liability Act (CERCLA). Under SARA provisions, permanent treatment of the contaminated soil and debris is being emphasized rather than the use of nontreatment containment systems such as covers, grout walls, and similar methods. Because of this, a program similar to the RCRA BDAT evaluations is being conducted for SARA remediation technologies including S/S. Mixtures of soils contaminated with selected chemicals were solidified/stabilized and tested to evaluate performance of S/S technology for treating contaminated soils. The test soil being used is a mixture of clay, sand, silt, topsoil and aggregate. As can be seen from Table III, solidification/stabilization was effective for reducing the leaching concentrations of arsenic, copper, lead, nickel, and zinc. No conclusion could be made from the chromium data since the initial concentrations were low.

2.3 SUPERFUND INNOVATIVE TECHNOLOGY EVALUATIONS (SITE)

The U.S. EPA SITE Program provides for demonstration and evaluation of innovative technologies to remediate Superfund sites. Currently six S/S processes are being evaluated (Table IV). The vendors are allowed access to the sites and pay for their operational and treatment expense. The U.S. EPA pays for site preparation work and sampling and analytical cost. Results will provide information on how well S/S can be expected to permanently treat contaminated soils. The evaluations will also help make better extrapolation of laboratory tests results to field conditions.

3.0 PROCESS SELECTION CONSIDERATIONS

3.1 IMPORTANT FACTORS

Factors important in the selection, design, implementation, and performance of processes and products are: waste characteristics (chemical and physical), processing requirements, S/S product management objective, regulatory requirements, and economics. These and other site-specific factors (i.e., location, condition, climate, hydrology, etc.) must be carefully considered to ensure acceptable performance.

3.1.1 Waste Characteristics

The chemical effects of some compounds can reduce the strength of the binder/waste mix, while some compounds can accelerate or retard the S/S curing rate. Temperature and humidity can also retard or accelerate curing. Size and shape of particles can affect the viscosity of the mix. The impact of strength on leachability has not been determined.

3.1.2 Process Type/Quality Assurance and Control

It is important to assess what process type and specific process requirements are required before selecting an S/S technology. For example, a waste-binder can be controlled and mixed more easily in a drum or in a plant process than in the in-situ solidification of a pit, pond, or lagoon. The performance of a process is related to the extent of mixing. More techniques are needed to determine mixing effectiveness. An effective real time Quality Assurance/Quality Control program may need to focus on indirect monitoring techniques (metering equipment, reagent quality and pilot test cells, operator experience, etc.) with then on-line sampling.

3.1.3 Treatment Objectives

The performance goals of the process must be established, for example, strength or leachate reduction required. The ultimate disposal condition must also be determined.

3.1.4 Regulatory Factors

Hazardous waste management regulations in the United States will be critical to the success of S/S. Processes can be altered to meet different performance criteria, which will become increasingly stringent, as regulations become more stringent. S/S will be competing with other treatment technologies to meet these regulatory criteria.

3.1.5. Costs

Costs will depend on site-specific conditions. Important are the waste's characteristics, type of process, disposal requirements and other special factors. What is the physical form and chemical make-up of the waste? Is pretreatment needed? Is transportation of raw materials and/or are finished S/S products required? Which S/S process is needed? What special health and safety requirements are needed? What is the quality assurance/quality control cost involved? What regulatory criteria must be met? Each of these factors must be considered. As regulatory criteria become more demanding, the costs of acceptable solidification processes may increase.

4.0 STUDIES NEEDED FOR S/S AS A TREATMENT TECHNOLOGY

For S/S technology to be effective in managing hazardous waste, proposed processes must be properly selected, formulated, and used. Improved knowledge of process selection considerations and the interactions among the various candidate binders and waste types is critical to the successful use as an acceptable treatment technology.

Studies are needed:

- to determine the long-term physical-chemical stability of S/S products when placed on the land;
- to determine how and under what conditions S/S products should be placed on the land to ensure long-term environmental protection;
- to more accurately predict and measure the performance of S/S processes and products;
- to provide a correlation between regulatory criteria and real world situations;
- to evaluate the effectiveness of protocols (e.g., leaching tests, durability test, etc.) to characterize S/S products, provide effective measurement techniques, and correlate results of such tests with performance in the field;
- to determine if micro-encapsulation is an effective technique without bonding;
- to determine the effectiveness of processes and equipment to effectively solidify/stabilize contaminated soil and/or lagoons; the effectiveness of mixing methods; and the resulting solidified/stabilized soil performance at varying soil depths;
- to determine the amounts of organic compounds that can be included in inorganic waste streams without requiring pretreatment before S/S;
- to determine how effectively S/S processes treat residuals from other alternative treatments.

5.0 SUMMARY

Solidification/stabilization is being evaluated by the U.S. EPA as a best demonstrated available technology for treating hazardous waste and contaminated soils and debris. Future use of the technology in the United States will depend on how well it performs compared to other available treatment processes. The evaluations and current research being conducted will provide some answers regarding performance, however, additional studies are required for a better scientific understanding of S/S. Whether or not S/S becomes an important technology for treating hazardous waste and contaminated soils in the U.S. ultimately depends upon regulatory requirements and the capability of the technology to meet these requirements. As performance criteria become more severe, S/S developers may need to improve their processes. The future technology direction is showing progress. In the case of RCRA waste, S/S may be the only acceptable method to treat selected inorganic waste and hazardous residues from incinerators and other treatment processes. In the case of contaminated soils and debris, S/S offers a relatively inexpensive method for treating large areas in situ. However, the capability of the technology to perform satisfactorily over long periods of time has yet to be determined.

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5. Weitzman, L., Hammel, M., and Barth, E: Evaluation of Solidification/Stabilization as a BDAT for Contaminated Soils, Proceedings of Fourteenth Annual HWERL Symposium, Cincinnati, OH (1988)

6. Weitzman, L. et.al.: Volatile Organic Emissions from Stabilized Hazardous Waste. Final Report. U.S. EPA Contract #68-02-3994 (1989)

Table I. CURRENT U.S. EPA SOLIDIFICATION/STABILIZATION RESEARCH PROJECTS

Project Title	Objective
Evaluation of S/S for Treating Ash Residues, Hazardous Sludges, and Contaminated Soils	Evaluate efficacy for treating several waste types from each category
Evaluation of Factors Affecting Solidification/Stabilization Process	Determine effects of interfering agents on performance of S/S
Investigation of Comparative Test Methods for Solidified - Waste Characterization	Develop and evaluate methods for testing performance of solidification processes
Study of Morphology and Microchemistry of Solidified/Stabilized Waste	Investigate bonding mechanisms
Air Emissions from Waste Stabilization	Determine air emissions from S/S processes
Use of S/S in Treatment Train	Determine efficacy of S/S following incineration, low temperature desorption, and soil washing
Potential Use of Organophilic Clays and Other Organic Binders	Determine treatment potential of organic binders
Construction Quality Assurance/ Quality Control Parameters	Development of QA/QC procedures for real time field use

TABLE II. EXAMPLE OF U.S. EPA RCRA HAZARDOUS WASTES FOR WHICH S/S IS BEING EVALUATED AS A TREATMENT TECHNOLOGY

Waste Code	Description of Waste	Pollutant of Concern for S/S
K048-52	Dissolved air flotation (DAF) float from the petroleum refining industry	chromium, lead
K061	Emission control dust/sludge from the primary production of steel in electric furnaces	chromium, lead, cadmium
K046	Wastewater treatment sludges from manufacturing formulation and loading of lead-based initiating compounds	lead
F006	Metal finishing sludges	cadmium, chromium, lead, nickel, silver
F012, F019	Metal finishing sludges	cadmium, chromium lead, nickel, silver
K022	Distillation tar (treated)	chromium, nickel
K001	Wood preserving sludges (treated)	lead

TABLE III. CONTAMINATED SOIL (SARM) TCLP RESULTS (mg/l) FROM U.S. EPA SARA BDAT STUDY

Metal	Raw	Treated
As	6.4, 9.6	ND, ND
Cd	33.1, 35.3	ND, ND
Cr	No, .06	.07, .07
Cu	80.7, 10.0	.09, .17
Pb	19.9, 70.4	ND, .37
Ni	17.5, 26.8	ND, ND
Zn	359, 396	.69, .74

Source of data: Weitzman, Hammel, Barth (5)

TABLE IV. SOLIDIFICATION/STABILIZATION PROCESSES BEING EVALUATED IN THE U.S. EPA SITE PROGRAM

Chemfix Technologies, Inc.
Soliditech, Inc.
Silicate Technology, Inc.
Hazcon, Inc.
International Waste Technologies
Separation and Recovery Systems

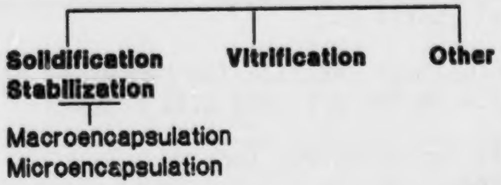
OVERVIEW OF SEMINAR

- Introduction
- Descriptions of S/S technologies
- Description of vitrification technology
- Technology screening procedures
- Physical testing methods
- Chemical testing methods
- Field implementation procedures
- Quality assurance procedures
- Case histories

OVERVIEW OF INTRODUCTION SECTION

- Definitions
- Range of immobilization technologies
- Process descriptions
- Where being utilized
- Regulations

IMMOBILIZATION TECHNOLOGIES



Solidification Stabilization

- Macroencapsulation
- Microencapsulation

Vitrification

Other

SOLIDIFICATION

VS.

STABILIZATION

HIERARCHY OF HAZARDOUS WASTE MANAGEMENT

- Waste minimization/reduction
- 3-R's
    - recovery
    - reuse
    - recycle
- Treatment
    - destruction
    - reduction
      mobility, toxicity, volume
- Storage

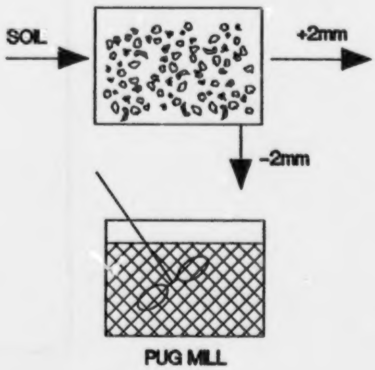
GOALS OF S/S PROCESSES

- Reduce pollutant mobility
- Decrease surface area (reduce loss or transfer of contained pollutants)
- Produce solid with no free liquid
- Improve handling and physical characteristics of waste

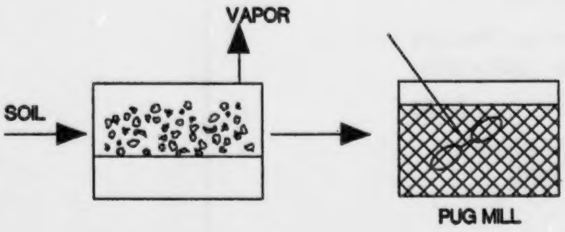
WHY CONSIDER S/S?

- Minimizes leachate rate from metal waste
- Lower cost than other immobilization technologies, especially if done in situ

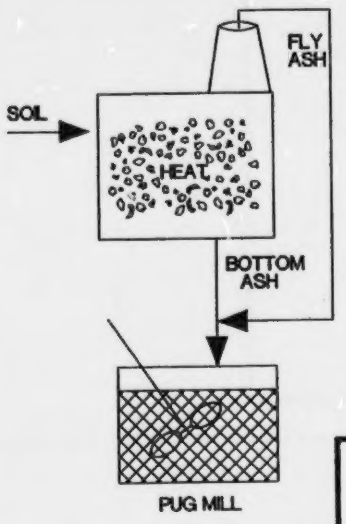
TREATMENT TRAIN
SOIL WASHING FOLLOWED BY S/S


SOIL
+2mm
-2mm
PUG MILL

TREATMENT TRAIN
THERMAL DESORPTION FOLLOWED BY S/S


VAPOR
SOIL
PUG MILL

TREATMENT TRAIN
INCINERATION FOLLOWED BY S/S



CURRENT STATUS OF S/S UTILIZATION IN U.S.A.

- 25% of Superfund sites in FY 1988
- Several RCRA waste codes for BDAT
- Being considered for MWC ashes

EXAMPLES OF U.S. EPA RCRA HAZARDOUS WASTES FOR WHICH S/S IS BEING EVALUATED AS A TREATMENT TECHNOLOGY

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K046'	Wastewater treatment sludges from manufacturing formulation and loading of lead-based initiating compounds	lead

EXAMPLES OF U.S. EPA RCRA HAZARDOUS WASTES FOR WHICH S/S IS BEING EVALUATED AS A TREATMENT TECHNOLOGY

(continued)

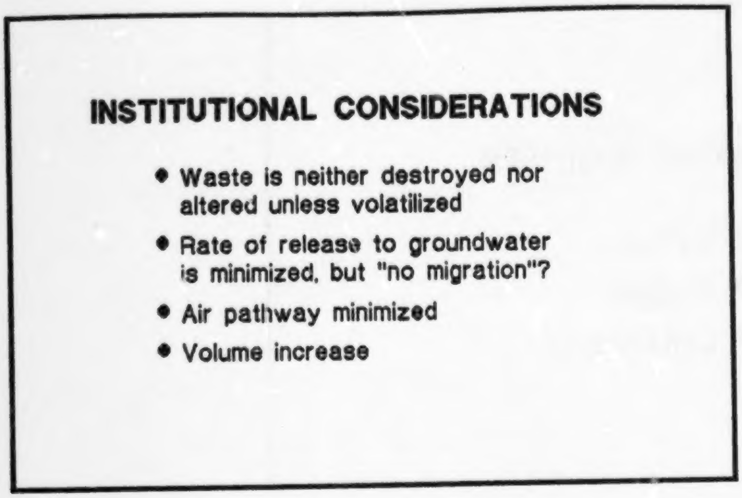
Waste Code	Description of Waste	Pollutant of Concern for S/S
F006	Metal finishing sludges	cadmium, chromium, lead, nickel, silver
F012, F019	Metal finishing sludges	cadmium, chromium, lead, nickel, silver
K022	Distillation tar (treated)	chromium, nickel
K001	Wood preserving sludges (treated)	lead

CURRENT STATUS OF S/S UTILIZATION FOR RADIOACTIVE SITES

- NRC has guidance for low level disposal

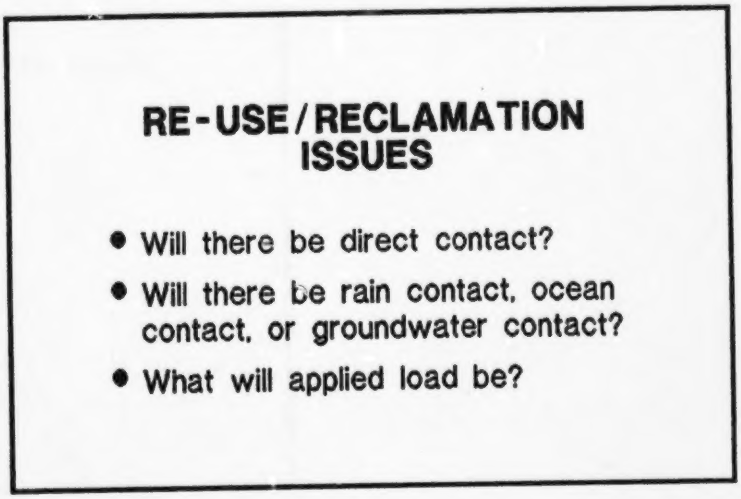
SITE PROGRAM DEMONSTRATIONS

HAZCON
IWT
SOLIDITECH
CHEMFIX
STC
SRS



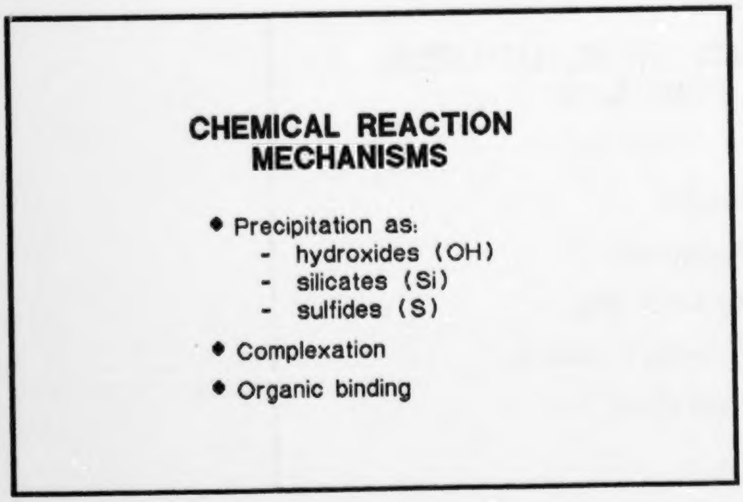
INSTITUTIONAL CONSIDERATIONS

- Waste is neither destroyed nor altered unless volatilized
- Rate of release to groundwater is minimized, but "no migration"?
- Air pathway minimized
- Volume increase



RE-USE/RECLAMATION ISSUES

- Will there be direct contact?
- Will there be rain contact, ocean contact, or groundwater contact?
- What will applied load be?



CHEMICAL REACTION MECHANISMS

- Precipitation as:
  - hydroxides (OH)
  - silicates (Si)
  - sulfides (S)
- Complexation
- Organic binding

BINDING AGENTS

- Inorganic
- Organic
- Combination

BINDER MATERIAL UTILIZED FOR S/S

Inorganic

- Cement
- Lime
- Kiln dust
- Fly ash
- Silicates
- Clay
- Zeolite

BINDER MATERIAL UTILIZED FOR S/S

Organic

- Asphalt
- Surfactant
- Modified clay
- Activated carbon
- Polyesters

BINDER MATERIAL UTILIZED FOR S/S

Organic
(continued)

- Polyethylene
- Resin
- Epoxide
- Urea formaldehyde

SUMMARY OF 1986 TSDF SURVEY

Process Type	No. Units	Quantity (tons)	Capacity (tons)
Cement	50	281,695	3,880,905
Pozzolanic	37	351,635	2,111,111
Asphaltic	1	0	100,000
Thermoplastic	0	0	0
Organic Polymer	1	157	157
Macroencapsulation	3	308	2,926
Other	15	4,110	11,247
Total	107	656,104	6,106,346

REGULATIONS

RCRA/HSWA
CERCLA/SARA

GOALS OF S/S TREATMENT

Delist → **Subtitle D**

BDAT → **Subtitle C**

HAZARDOUS WASTE MANAGEMENT REGULATIONS

- RCRA
  - no free liquids
  - 50 p.s.i.
  - liquids - Release Test
- HSWA
  - BDAT

UNCONTROLLED HAZARDOUS WASTE SITE REGULATIONS

- CERCLA
  - cost effective remedy
- SARA
  - treatment preference

S/S CONSIDERATION AS A REMEDIAL TECHNOLOGY

- Treatment by S/S can achieve substantial reduction of mobility
- S/S treatment may represent the best balancing of the selection criteria (including low level organics)
- Management considerations

COST ESTIMATION

Mobilization	$100,000-200,000/site
Excavation	$10-50/cy
Processing	$50-100/cy
Disposal	$100-250/cy

DESCRIPTIONS OF SOLIDIFICATION AND STABILIZATION (S/S) TECHNOLOGIES

SECTION 2

Abstract 2-2
Slides 2-12

DESCRIPTIONS OF SOLIDIFICATION/STABILIZATION TECHNOLOGIES

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Riverdale, Illinois

1.0 INTRODUCTION

As a result of the 1984 RCRA amendments, no liquids and only limited amounts of chemical wastes may be placed in hazardous waste landfills without being chemically altered prior to disposal. This ruling has resulted in increased quantities of waste being solidified or stabilized. This paper gives a brief description of the S/S industry and the processes that are used.

"Solidification/Stabilization" (S/S), also referred to as waste fixation, is a relatively simple process. The waste is mixed with a binder or mixture of binders. The mass is then cured to form a solid matrix that can be safely disposed in a landfill or other containment.

While solidification and stabilization are mechanically very simiiar, they are really two different industries. Solidification is the traditional industry which takes a waste that contains free water and solidifies it by reacting it with a binder such as cement or lime. No effort is made to reduce the leachability of any hazardous constituents that may be present in the waste. The goal is only to react all free liquids in the waste with the binder. The stabilization industry is emerging in response to the recent "Land Ban" regulations which are restricting specific categories of waste from hazardous waste landfills unless they are pretreated to a minimum leachability standard. Wastes are stabilized by mixing them with specific types and, usually larger quantities, of binder to fix the hazardous constituents in the solid matrix. The intent in this case is to reduce the leachability of hazardous constituents as measured by the Toxicity Characteristic Leaching Procedure (TCLP).

It is important to differentiate between these two unique industries when evaluating the industries and assessing the impact that regulations will have on them. The initial restrictions on the landfill disposal wastes containing free liquids created the solidification industry. Until this ban, very few wastes were treated in this way prior to disposal. Such treatment can be achieved by the addition of relatively small amounts of binder which converts the waste into a soft granular solid. Such a solid can be readily loaded onto bulk carriers and shipped to a landfill for disposal.

Now, the "Land Ban" restrictions are requiring that more types of waste be treated beyond the point of just chemically binding with free liquids. The treatment must also immobilize contaminants. Such treatment usually requires the addition of more binder and often (but not always) produces a hard, monolithic solid mass that is analogous to soft concrete. Handling such a mass is much like handling large, irregularly shaped concrete chunks which cost more to transport than does the original waste. As a result, facilities that are close to hazardous waste landfills are in a better position to stabilize wastes than are those that have to ship the treated waste.

For the purpose of determining and minimizing organic air emissions, the S/S process can be broken down into three distinct steps:

1. mixing
2. curing
3. storage and landfilling

The mixing step is the basic operation where the waste is placed into a mixer and combined with the binder. The mixer is normally designed for ease of loading of the waste and binder and removal of the mixed material. Once mixed, the material is allowed to cure, at which time chemical reactions between the waste and binder harden the mixture. Curing can take place in the mixing vessel (as when mixing occurs in a drum or other disposable vessel) a temporary storage area, or directly in the landfill where the waste is ultimately placed. It can take as little as a few hours to as 30 days or more.

The final step, storage and disposal, is the goal of the S/S process. The material has hardened and if the binders are appropriate for the application, the waste has been stabilized. At this point, the material may be placed in a landfill and covered.

Until relatively recently, the mixing of wastes and binder has been done in open pits, trenches and bunkers. These do not lend themselves to proper collection and control of air emissions. S/S processes can and do produce both particulate and organic air emissions. Particulate control is being required with increasing frequency by states and by federal regulations. Organic emissions from these processes will soon be regulated on a national level by EPA.

Generally speaking, the type of mixing equipment used will influence how well the organic air emissions are collected and controlled, and the type of binder used will influence the point in the process where they will be released. The mixing equipment's effect on emissions is illustrated by the two extremes of a completely open and a completely closed mixing system. Emissions from a completely open mixing system, an open-pit mixer for example, can be complex, requiring the installation of large enclosures. The enclosures need to be designed so that the waste and binder can readily be added to the mixing vessel, or pit, and the mixture can be removed as well. By comparison, it is relatively easy to duct an enclosed mixer to an air pollution control device. In either case, once the Organic Air Emissions are collected, their removal or destruction can be achieved using readily available equipment.

The type of binder used, determines the temperature of the system during mixing or curing. For example, a binder, based on quicklime (CaO), will get very hot when mixed with an aqueous waste. The high temperature will cause a rapid release of the organic constituents. Because the solidified/stabilized product will then have lost most of the volatile constituents during mixing, it will release fewer organic air emissions during curing, storage, and disposal. If the mixing must occur in open equipment, then a binder with a low heat release is desirable. This will result in minimizing the organic air release until the waste can be placed in a sealed and capped landfill.

Clearly, in order to control air emissions during mixing it is necessary to capture them while mixing is going on and during the handling of the waste before and after mixing. If a greater degree of control is required it may be necessary to capture the emissions during the curing phase as well. Control of organic air emissions, once captured, is straightforward. Standard technologies such as condensation, adsorption, thermal incineration, or catalytic incineration can be used to collect or destroy the organic air emissions captured. Particulate emissions control, while straightforward, does require special consideration since the particulate is wet and includes cement or other natural or synthetic pozzolans which can clog and damage the collection equipment.

The following sections discuss the types of mixing equipment and binders commonly used in commercial S/S processes.

2.0 STABILIZATION PROCESS DESCRIPTION

The various stabilization processes commonly used are described in detail by Cullinane and Jones (5). The following discussion is designed merely to offer an overview of the steps involved. S/S can be broken down into two components. The first is the type of process used to mix and handle the wastes and binders, and the second is the type of binder used. With very few exceptions, each mixing method can be used for each type of binder. The exceptions are discussed in Section 4.

2.1 PROCESS TYPES

2.1.1 Open Pit or Trench Mixing

This is the simplest and most commonly used S/S process. The waste is placed in a lined trench, lagoon, or pit, and the binder is mixed with it. Most frequently, a backhoe or a similar device is used to mix the waste and binder. This process is frequently used to S/S waste or soil at field remediation as well as at permanent locations.

S/S is often used in field remediation to solidify a pond or lagoon in place. The binders are then simply dumped into the pond or lagoon and a backhoe is used to blend them in. The solidified material may then be either left in place and capped or excavated and landfilled elsewhere.

When open trench mixing is used at a fixed location, as in a treatment facility, it is typically performed in a lined trench made of concrete. The trench is sometimes placed in a large, open building to protect it from the elements and can be above or below grade. Truckloads or drumloads of the waste are emptied into the trench and the binder is added, either with a backhoe, front-end loader or through a bulk solids handling system. The mass is then mixed with either a backhoe arm or with the blade of the front-end loader. When the front-end loader is used, the mixing is performed by kneading the waste and binder against the wall of the trench. After the mass is mixed, the backhoe or front-end loader is used to load the pasty mass into a truck or roll-off container for transport. The mixture is then, typically taken to a storage area for curing or to the landfill itself.

After the mass hardens, usually within one day, it is tested (if required by regulations) and, if it satisfies the regulations, it is landfilled.

2.1.2 In-Situ S/S--(Egg Beater Mixing)

This process is a recent development in which soil is mixed with the binder in-place, without excavation. A mobile process is used that combines several drills with bits up to six feet in diameter on one truck or trailer. The process literally drills down into the contaminated soil and as the drill penetrates it, binder is injected. The drill mixes the binder and soil. If emission control is needed, a shroud fits over the drilling assembly.

2.1.3 In-Drum Processing

This is a small-scale process in which the binder and waste are mixed in a drum or other disposable container. An open-head drum with a standard drum mixer mounted in it is typically used for this application. After mixing, the mixer is removed and waste-binder matrix allowed to set. The lid is put on the drum and the waste, drum and all, is disposed of in a landfill.

2.1.4 Reactor Processing

This process is a simple scale-up of the in-drum processing system. The bulk waste material and binder are mixed in mechanical mixing vessels. The vessel can be either open or closed top and should have provisions for loading and discharging the solids and waste.

2.1.5 Batch and Continuous Type Closed-Vessel Processing

This process is similar to Reactor Processing with the exception that the reactor is totally enclosed to facilitate collection of the air emissions during mixing. The reactor will generally be purged with a controlled air flow or, if the organic can form an explosive mixture, an inert gas such as nitrogen. The mixing vessel can be a simple closed reactor with facilities for loading and discharging solids or a continuous mixer such as a ribbon mixer or pug mill.

2.1.6 Mobile Plant Processing

Any of the processes can be mounted on a trailer or truck and operated in the field. The vapor collection and control equipment, if needed, would also have to be mobile. The concepts for mobile plant processing are identical to those for similar fixed systems and does not need to be discussed separately.

2.2 SOLIDIFICATION/STABILIZATION AGENTS

In order for S/S to be effective, the binder used must:

a. React with free water in the waste and form a solid.
b. Bind with the metals and organics to reduce their chemical nature and/or their leachability.
c. Bind with the Organic Air Emissions in the waste to reduce their chemical nature and ability to vaporize.

Ideally, the chemical processes used should involve chemical reactions with the hazardous components in the waste; however, practically, this does not happen very often for all components. Frequently, the binder reacts with the free water and metals in the waste and the resultant matrix traps the organic constituents so that they cannot be readily released. Laboratory tests (1,3) have shown that while the typical inorganic processes appear to immobilize the metals well, they do not reduce the emissions of the volatile organic compounds significantly. Many simply absorb or absorb the free liquid without reacting with it.

Sorption is often used as a means of solidifying wastes. It is not, by itself, considered to be a stabilization process since it does not meet the criterion that free water must be chemically combined into a solid matrix. Sorption is frequently used to clean up hazardous materials spills. The inorganic sorbents are sometimes used when the waste is a free flowing liquid to make it easier to handle. In this case, the absorbent and waste would then be stabilized by mixing it with other agents such as cement to make a solid. Common absorbents are expanded clay and treated organic materials such as corn-cobs, or simple sawdust. Organic sorbents are generally used to collect liquids when the product will be sent to an incinerator for disposal.

Binders fall into two categories, inorganic and organic. They are also identified by their chemical mechanism. By far, the most commonly used binders are inorganics such as cement kiln dust, flyash, and other waste materials that can chemically react with water. Because of the large amounts of binder that are often required to solidify/stabilize a waste, cost of the raw materials dominates the selection process. With development of new regulations, leaching and organic air emissions, the binder's performance will, probably, assume greater significance.

The vast majority of commercial S/S is performed with inorganic binders. While a number of organic binders have been proposed, and marketed, their performance has not been fully demonstrated to date. This coupled with their high cost have kept them from making significant inroads into the market. Within both categories, a variety of proprietary binders have been proposed or are marketed by vendors. The majority of the wastes solidified at present uses generic binders discussed below.

Table 2-1 lists some of the proprietary binders presently available. As can be seen most are sufficiently similar to generic ones that their behavior regarding organic air emissions can be readily determined from the discussions below which restrict themselves to generic binders.

2.2.1 Inorganic Binders

As mentioned earlier, binder is typically selected on the basis of cost. As a result, whenever, possible, a waste material that reacts with water will be used. Commonly used inorganic binders are:

- cement kiln dust
- lime kiln dust--typically contains significant amounts of quicklime
- coal fly/bottom ash
- mixtures of the above

When these are unavailable or unsuitable, commercial products are used. These include:

- natural pozzolans
- lime (usually a grade of agricultural lime) mixed with flyash
- portland cement, usually mixed with an inert flyash

The solidification of wastes is analogous to the manufacture of concrete, which is a mixture of coarse aggregate (gravel), fine aggregate (sand), and a binder (cement). Water chemically reacts with the binder to form a solid matrix of the components. In solidification, the waste supplies the water and (depending on its composition) a greater or lesser fraction of the aggregate. Clearly, the two mixtures can be formulated differently. When manufacturing concrete, strength is essential. As a result, the binder, water, aggregate and cement are mixed in proportions that optimize this property. The purpose of S/S is to chemically react the water to form a solid, and to immobilize the contaminants. The product only has to achieve a minimal load bearing strength. The hazardous waste regulations only require an unconfined compressibility strength of 50 psi.

It is, clearly, impossible to discuss all combinations of binders herein; however, for the purpose of ORGANIC AIR emissions, this is not necessary. Regardless of the binder formulations used, the concepts are the same and can be illustrated by the following examples:

1. aqueous waste solidified/stabilized with portland cement/flyash
2. aqueous waste solidified/stabilized with lime kiln dust/flyash
3. aqueous waste solidified/stabilized with agricultural lime/flyash

Flyash from some coal-fired power plants are very reactive and will set-up, much like cement, when mixed with water. Such flyashes are sold in commerce and commonly used as a concrete additive. They can be considered to behave in a similar manner to portland cement with regards to organic air emissions. They type of flyash discussed here, is the less valuable variety. When mixed with the lime or lime kiln dust, it participates in the chemical reaction. When mixed with portland cement, however, it is relatively inert. It serves as a source of aggregate and as a bulking agent to absorb the free water.

TABLE 2-1. COMMERCIAL WASTE STABILIZATION PROCESSES

Vendor	Process Name	Ingredients	Comments
Chemfix, In	Chemfix	Cement + Soluble Silicates	Probably does not fix most volatile organics
IU Conversion	Sealosafe Stablex	Silicates	Probably does not fix oils solvents, grease volatile organics
Dravo Lime	Calcilox	Glassy Slag and Scrubber Sludge	Designed to fix scrubber sludge. probably does not fix most volatile organics
Envirotech (Subsid. of Chemfix)	Envirotech	Cement and Silicates	U.S. Patent 3,837,872
Velsicol	Velsicol	Fly Ash, Scrubber Sludge and Cement	Claims to stabilize organics; not specific
Stabitrol Corp	Terra-Tite	Cement	Probably does not fix most volatile organics
TRW Systems	--	1. Cement, Plaster and Lime	Does not fix volatile organics
		2. Polybutadiene Resin	May Work for organics; very costly
U.S. Gypsum	Envirostone	Gypsum	Does not fix volatile organics

2.2.2 Organics

The organic binders are rarely used commercially because of their high cost compared to inorganics. They have been proposed for use on wastes containing organic constituents. Organic binders can be broken into two broad categories--(1) bitumen and (2) polymers.

As much as S/S with portland cement is analogous to the manufacture of concrete, the use of asphalt/bitumen is analogous to the manufacture of asphalt concrete--common paving asphalt. In the latter case, the bitumen or tar replaces the cement to bind the aggregate. Bitumen is not a suitable binder for wastes containing water. In fact, the solid material has to be dried prior to mixing with the hot tar. This process has only been used to a limited extent for solidifying soils containing low level radioactive materials and not for hazardous wastes. As a result, this binder will not be discussed separately here.

Polymeric binders have been proposed for the S/S of hazardous wastes. In this application, the wastes are mixed with a material such as expanded clay or flyash to absorb free liquids. The mass is then mixed with a polymer or polymer precursor and allowed to harden. Polymers that can be used include epoxy, polyesters, polyolefins, and urea-formaldehyde. Polymeric binders do not react chemically with most types of wastes. Rather, they encapsulate the hazardous constituents and prevent them from being released to the environment. Polymers typically cost on the order of 25 cents to several dollars/lb. This could translate to a cost of $500 and up per ton of waste stabilized just for the binder. Adding the cost of labor, capital, and operating costs, could readily bring the cost of stabilization with polymeric materials up to that for incineration. It is, therefore, unlikely that polymers will be used as binders to a significant extent in the foreseeable future. They will not be discussed further herein.

2.2.3 Organic/Inorganic Mixtures

Combinations of inorganic and organic binders have been proposed in the past to S/S hazardous waste. These include diatomaceous earth with cement and polystyrene; polyurethane and cement, and polymer gels with silicate and lime cement. As with organic binders, these are relatively expensive for the same reason as the polymeric binders. They will not, likely be used in large volumes in the foreseeable future and will not be discussed further herein.

2.3 INDUSTRY TREND

S/S appears to be a growing industry. At present, it is used to eliminate free water from wastes and to immobilize heavy metals to make them suitable for land disposal. As land ban rules take effect, it will be necessary to pretreat more types of waste to reduce their leachability. EPA has specified several types of pretreatment technologies such as incineration, S/S, and chemical treatment as a "Best Demonstrated Control Technology" (BDAT). Of those proposed, industry has had the most experience with incineration and S/S. Incineration has shown itself to be useful for the destruction of organic contaminants but with limited applicability for inorganics, especially heavy metals. S/S has had good success in immobilizing heavy metal and other inorganic contaminants. As the BDAT regulations come into effect for increasingly more categories of waste, the amount of waste being treated in this way will continue to grow.

It is not likely that new types of binders will be used in the foreseeable future. By and large, inorganic binders based on waste products such as cement kiln dust, lime kiln dust or flyash will continue to be used. In applications where waste materials are unavailable or unsuitable, high volume, relatively low cost and readily available inorganic binders such as portland cement or lime will continue to be the binder of choice. These have been shown to satisfactorily immobilize metals (based on current testing procedures) and there appears to be little incentive to use other, more costly binders.

Organic binders have been available for over a decade. They have generally been proposed to stabilize wastes that have a high organic content, the very wastes that are addressed by this document. It does not, appear, however, that such binders will be used to a significant extent in the foreseeable future.

As discussed above, asphaltic binders are not suitable for hazardous waste application (they cannot tolerate water). There does not appear to be any reason why they should be used in this application in the foreseeable future.

Polymeric binders are not likely to be used for stabilizing hazardous waste because of their very high cost. The raw materials of even the least expensive polymer could cost more than $0.25/pound or $500/ton. Many binders could cost even more. By the time the handling and other costs are added, S/S with this type of binder could easily cost $1,000 or more per ton. At these costs, it would be more economical to pretreat a waste prior to S/S.

For example, an aqueous waste containing organics and heavy metals could be pretreated by a technique such as physical separation and air stripping to remove the volatile organics and then solidified/stabilized with cement kiln dust and flyash. If the organic content of the waste is higher, the waste could be incinerated and then the ash, containing the heavy metals could be stabilized with an inorganic, if necessary. Because of the existence of such alternate waste treatment techniques, it is unlikely that the use of high-cost binders, such as polymerics, will increase.

It is likely, however, that the types of equipment used for S/S will change. At present, the bulk of the processing is conducted in open equipment. Restrictions on organic emissions from these processes will probably shift the economics for many applications in favor of closed mixing equipment. The open systems would require large enclosures or hoods to capture organic emissions. The air flow through these systems would be relatively large with the inherently high costs associated in controlling these. Closed systems could be controlled by using much lower gas flow rates and, as a result, lower capital and operating costs for the portion of the S/S system. While the economics of each individual application will govern the processing equipment selected, it appears that regulations on organic air emissions will result in an increase in the use of enclosed systems.

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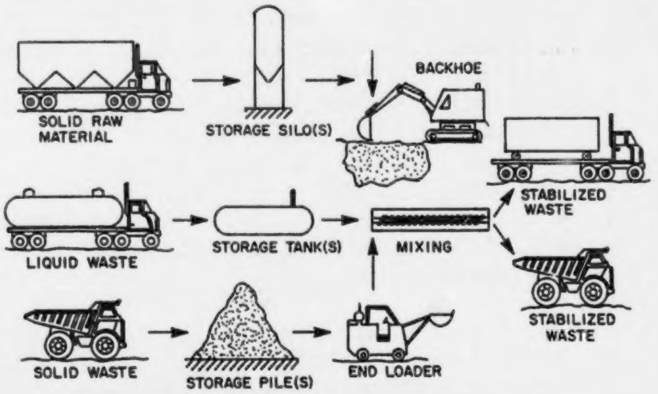
7. U.S. Environmental Protection Agency, "Air Emissions from Municipal Solid Waste Landfills - Background Information for Proposed Standards and Guidelines", Preliminary Draft. March 1988.

DISCUSS

- Waste characteristics
- Binders
- Mixing techniques (later talk)


SOLID RAW MATERIAL
STORAGE SILO(S)
BACKHOE
STABILIZED WASTE
LIQUID WASTE
STORAGE TANK(S)
MIXING
STABILIZED WASTE
SOLID WASTE
STORAGE PILE(S)
END LOADER

Generalized Pozzolanic Process Flow Diagram

BASIC APPROACH TO STABILIZATION OF INORGANIC CONSTITUENTS

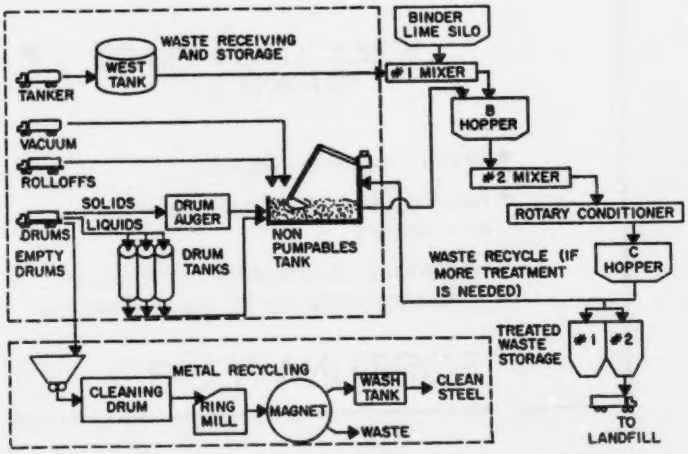
- Mix the waste with materials which convert the target constituents into relatively insoluble compounds
- Encapsulate the insoluble compounds in a matrix which reduces access by leachate and water
  - macroencapsulate
  - microencapsulate

MICRO- VS MACRO-ENCAPSULATION

- Blurred line
- Function of test method

KEY FACTORS

- Waste properties and composition
- Binders
- Mixing techniques


BINDER LIME SILO
WASTE RECEIVING AND STORAGE
WEST TANK
TANKER
#1 MIXER
B HOPPER
VACUUM
ROLLOFFS
#2 MIXER
SOLIDS
DRUM AUGER
LIQUIDS
DRUMS
ROTARY CONDITIONER
EMPTY DRUMS
DRUM TANKS
NON PUMPABLES TANK
WASTE RECYCLE (IF MORE TREATMENT IS NEEDED)
C HOPPER
TREATED WASTE STORAGE
#1
#2
METAL RECYCLING
CLEANING DRUM
RING MILL
MAGNET
WASH TANK
CLEAN STEEL
WASTE
TO LANDFILL

Flow Diagram of S/S Operation of Chem Met Services

IMPORTANT WASTE PROPERTIES

- Water content
  - physical state
- Hazardous constituents
  - inorganic
  - organic

WATER CONTENT

- Binder must chemically react with the water (solidification)
- Commonly done by hydrate formation

WHAT TAKES PLACE DURING S/S

- Water Chemically Reacts
- Hazardous constituents are made less soluble
- Hazardous Constituents are Encapsulated
  - Reduce contact with the environment

FORTUNATELY!

S/S BINDER TYPES

- Cement based binders
  - Portland cement
  - Cement kiln dust
  - Cement/flyash
  - Natural and artificial pozzolans
- Lime/limestone/quicklime
  - Lime kiln dust
  - Lime/flyash
- Absorbents
  - Hydro- and organo- philic clays
  - Wood chips, etc.
    generally not acceptable

(1 of 2)

S/S BINDERS

- Thermoplastic materials
  - asphalt/bitumen
  - thermoplastic polymers
- Thermosetting polymers
- Vitrification

(2 of 2)

POZZOLAN

Naturally occuring material that reacts to form a solid on addition of water or lime with water

VAST MAJORITY OF S/S WITH CEMENT BASED BINDERS

WHY?

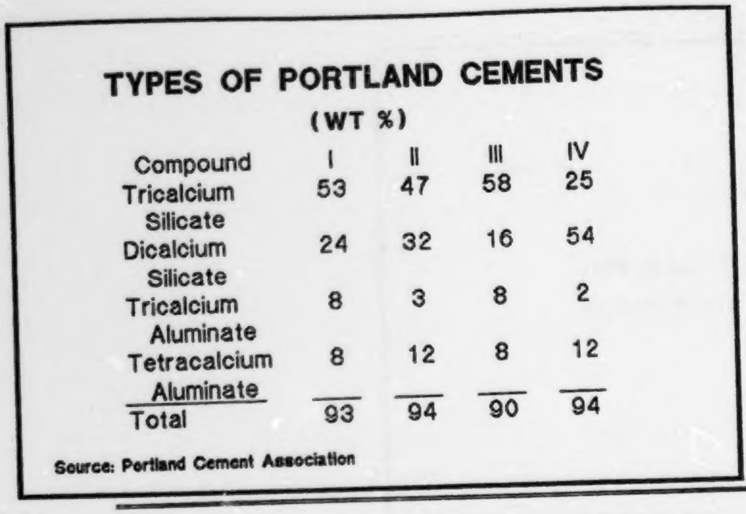
Consider Portland Cement

CEMENT BASED BINDERS

- Most common type
- Analogous to the manufacture of concrete
  - aggregate (coarse and fine)
  - water
  - cement
- Basic concepts apply

NORMAL APPROACH TO S/S

1. Chemically react all water
2. Insolubilize hazardous constituents
3. Encapsulate products



TYPES OF PORTLAND CEMENTS

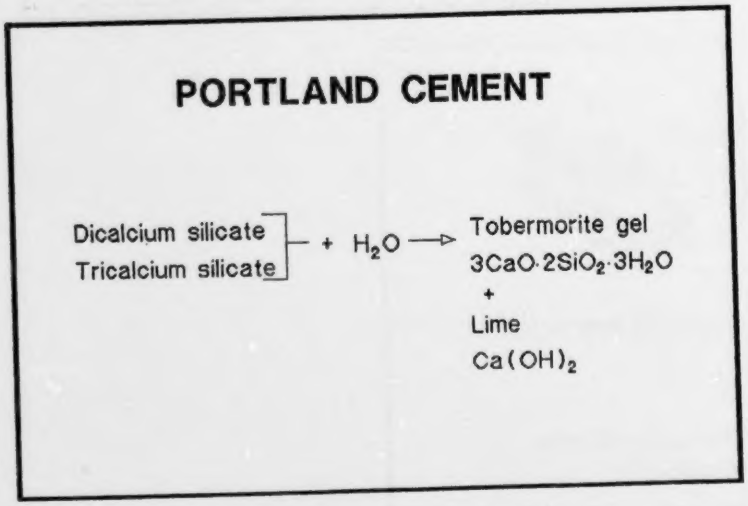
(WT %)

Compound	I	II	III	IV
Tricalcium Silicate	53	47	58	25
Dicalcium Silicate	24	32	16	54
Tricalcium Aluminate	8	3	8	2
Tetracalcium Aluminate	8	12	8	12
Total	93	94	90	94

Source: Portland Cement Association

$2(3Ca \bullet SiO_2)$ Tricalcium Silicicate	+	$6H_2O$ Water	$3CaO \bullet 2SiO_2 \bullet 3H_2O$ Tobermorite Gel	+	$3Ca(OH)_2$ Calcium Hydroxide
$2(2CaO \bullet SiO_2)$ Dicalcium Silicate	+	$4H_2O$ Water	$3CaO \bullet 2SiO_2 \bullet 3H_2O$ Tombermorite Gel	+	$Ca(OH)_2$ Calcium Hydroxide
$4CaO \bullet Al_2O_3 \bullet Fe_2O_3$ Tetracalcium Aluminate	+	$10H_2O + 2Ca(OH)_2$ Water Calcium Hydroxide	$6CaO \bullet Al_2O_3 \bullet Fe_2O_3 \bullet 12H_2O$ Calcium Aluminate Ferrite		
$3CaO \bullet Al_2O_3$ Tricalcium Aluminate	+	$12H_2O + Ca(OH)_2$ Water Calcium Hydroxide	$3CaO \bullet Al_2O_3 \bullet Ca(OH)_2 \bullet 12H_2O$ Tetracalcium Aluminate Hydrate		

Source: Portland Cement Association

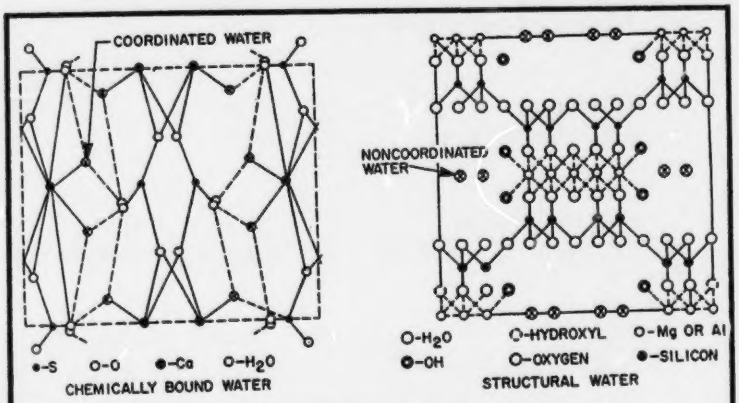


PORTLAND CEMENT

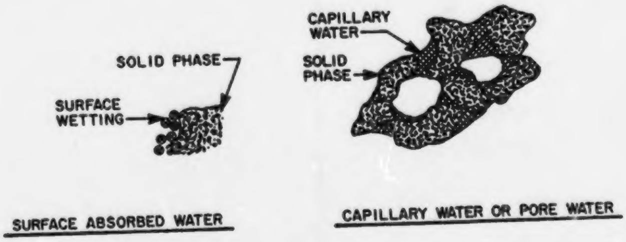
Dicalcium silicate
Tricalcium silicate

$+ H_2O \longrightarrow$ Tobermorite gel $3CaO{\cdot}2SiO_2{\cdot}3H_2O$ + Lime $Ca(OH)_2$

The cement ties up free water four ways


COORDINATED WATER
•-S
O-O
●-Ca
O-H₂O
CHEMICALLY BOUND WATER
NONCOORDINATED WATER
O-H₂O
●-OH
O-HYDROXYL
O-OXYGEN
O-Mg OR Al
●-SILICON
STRUCTURAL WATER

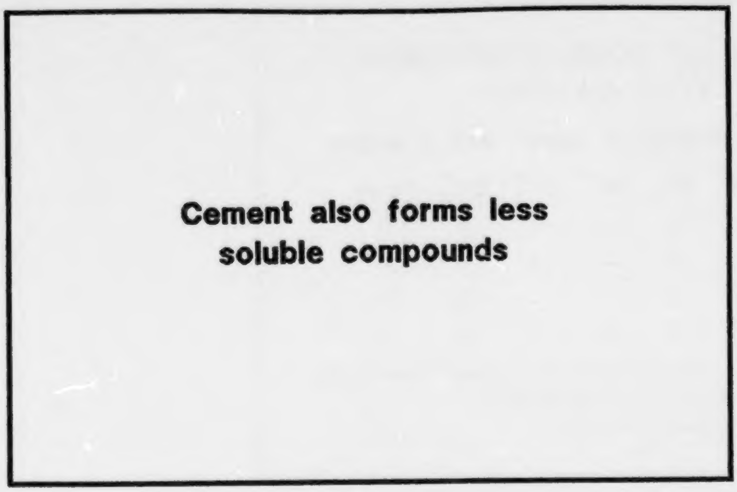
Mechanisms Retaining Water and Ionic Materials On and In Solid Phases (1 of 2)


SOLID PHASE
SURFACE WETTING
CAPILLARY WATER
SOLID PHASE

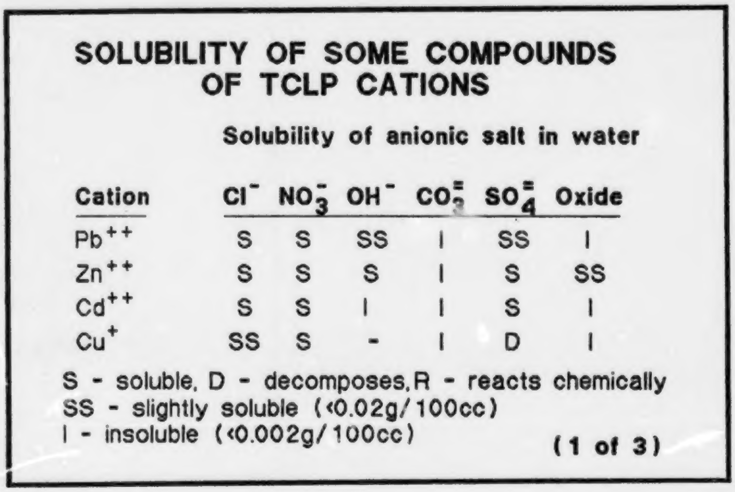
SURFACE ABSORBED WATER

CAPILLARY WATER OR PORE WATER

Mechanisms Retaining Water and Ionic Materials On and In Solid Phases (2 of 2)



Cement also forms less soluble compounds



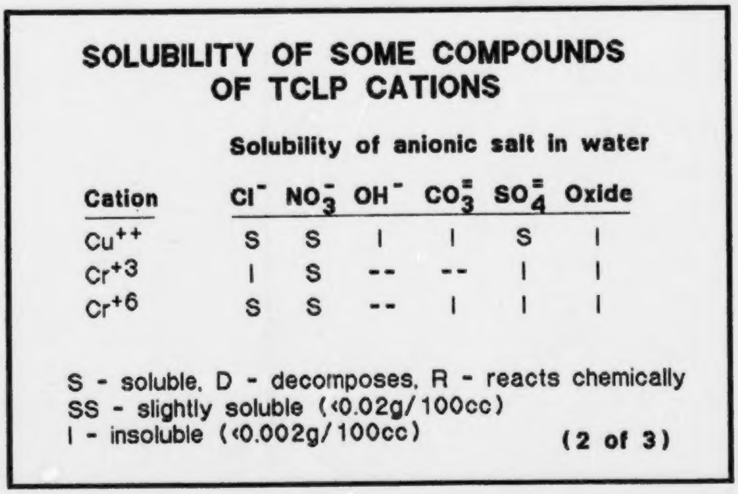
SOLUBILITY OF SOME COMPOUNDS OF TCLP CATIONS

Solubility of anionic salt in water

Cation	Cl^-	NO_3^-	OH^-	$CO_3^=$	$SO_4^=$	Oxide
Pb^{++}	S	S	SS	I	SS	I
Zn^{++}	S	S	S	I	S	SS
Cd^{++}	S	S	I	I	S	I
Cu^+	SS	S	-	I	D	I

S - soluble, D - decomposes, R - reacts chemically
SS - slightly soluble (<0.02g/100cc)
I - insoluble (<0.002g/100cc)

(1 of 3)



SOLUBILITY OF SOME COMPOUNDS OF TCLP CATIONS

Solubility of anionic salt in water

Cation	Cl^-	NO_3^-	OH^-	$CO_3^=$	$SO_4^=$	Oxide
Cu^{++}	S	S	I	I	S	I
Cr^{+3}	I	S	--	--	I	I
Cr^{+6}	S	S	--	I	I	I

S - soluble, D - decomposes, R - reacts chemically
SS - slightly soluble (<0.02g/100cc)
I - insoluble (<0.002g/100cc)

(2 of 3)

SOLUBILITY OF SOME COMPOUNDS OF TCLP CATIONS

Solubility of anionic salt in water

Cation	Cl^-	NO_3^-	OH^-	$CO_3^=$	$SO_4^=$	Oxide
Ni^{++}	S	S	--	I	S	I
Hg^+	I	D	--	I	D	I
Hg^{++}	S	S	--	I	S	SS
Ca^{++}	S	S	S	I	S	R

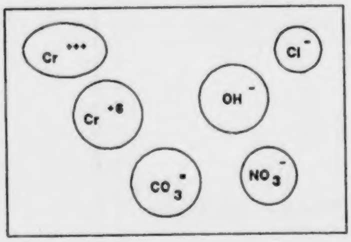
S - soluble, D - decomposes, R - reacts chemically
SS - slightly soluble (<0.02g/100cc)
I - insoluble (<0.002g/100cc)

(3 of 3)

CAVEATS

- Mixtures of compounds not always the sum of the components
- Components interfere with chemical reactions, set-up, and S/S
- Theory is a useful start

Solution is a Mixture of Ions



SOLUBILITY PRODUCT

$An_i \times Cat_j = K_{ij}$

$Ca^{++} \times OH^{-}$ = Constant

$Cr^{+3} \times Cl^{-}$ = Constant

$Cr^{+6} \times Cl^{-}$ = Constant

Mixtures form complex equilibrium

CONVERT TO INSOLUBLE SALTS

Summary

- Normal approach is to saturate with insoluble anion
  i.e. $CO_3^{=}$, OH^{-}
- Then combine with other, less soluble cations
  i.e. Ca^{++}, Si^{++}
  to form complex insoluble compounds
- Cement, lime, limestone, quicklime, and flyash - all sources of these anions and cations

NATURAL POZZOLANS

- Some forms of lava and coral
- Rarely used for S/S
- Does not appear to offer any operational or cost advantages in most situations

FLYASH WITH AND WITHOUT LIME
(Artificial Pozzolans)

- Some coal power plant flyashes will react with water and form hydrates, similar to cement
- Many more flyashes will do so with the addition of lime (or lime kiln dust)

FLYASH

- Contains
  - Silica
  - Alumina
  - Calcium oxide
- Most flyashes do not harden by themselves
- Many flyashes will harden when mixed with $Ca(OH)_2$ or cement
- A few contain enough $Ca(OH)_2$ to harden by themselves

Note: Flyashes can contain metals

LIME/FLYASH MIXTURES
(Artificial Pozzolans)

- Flyash supplies silicon
- Lime supplies $Ca(OH)_2$
- Results in properties chemically similar to cement

LIME BASED BINDERS

- Lime (slaked lime) $Ca(OH)_2$
- Quicklime CaO
- Limestone $CaCO_3$

$$\underset{\text{quicklime}}{CaO} + H_2O \rightarrow \underset{\text{lime}}{Ca(OH)_2}$$

$$\underset{\text{lime}}{Ca(OH)_2} + CO_2 \rightarrow \underset{\text{limestone}}{CaCO_3}$$

LIME KILN DUST

- Contains large amounts of quicklime (lime) - CaO
- Large temperature rise as it is mixed with water to form "slaked lime" $Ca(OH)_2$

WHEN USED WITH MATERIALS LIKE COAL FLYASH

- Calcium compounds react with the iron, silicon and other metals in an analogous manner as in portland cement
- Artificial pozzolans

AGRICULTURAL LIME

- Used to modify pH
- Modifies physical properties
- Generally limited ability to stabilize most metals

NOTE ON CYANIDES

- Alkalinity of cement and lime based binders is important in their stabilization
- If properly done, possible to fix them
- Chemistry is crucial

ADDITIVES / MODIFIERS

- Sodium silicate, $NaSiO_2$
  (water glass)
  - additional silicon
  - claimed to form NaSiAl gels
  - fills pores in product
  - does reduce leaching of contaminants at times

TYPES OF SORBENTS

- Flyash
- Limestone screenings
- Clays
- Zeolites
  (see book)

HYDRO- AND ORGANOPHILIC CLAYS

- Commonly used to absorb liquids prior to S/S
- Lab tests have indicated that some organophillic clays chemically bond to organic liquids
  - concern with bond strength
- EPA's policy is uncertain now
- In most cases the mechanism is merely physical absorption
- May have promise in combination with other binders i.e. absorb then bind with cement

NATURAL SORBENTS AND THEIR CAPACITY FOR REMOVAL OF SPECIFIC CONTAMINANTS FROM LIQUID PHASES OF NEUTRAL, BASIC, AND ACIDIC WASTES

Contaminant	Neutral Waste (calcium flouride)		Basic Waste (metal finishing sludge)		Acidic Waste (petroleum sludge)	
Ca	Zeolite	(5054)*	Illite	(1280)	Zeolite	(1390)
	Kaolinite	(857)	Zeolite	(1240)	Illite	(721)
			Kaolinite	(733)	Kaolinite	(10.5)
Cu	Zeolite	(8.2)	Zeolite	(85)	Zeolite	(5.2)
	Kaolinite	(6.7)	Kaolinite	(24)	Acidic F.A.	(2.4)
	Acidic F.A.†	(2.1)	Acidic F.A.	(13)	Kaolinite	(0)
Mg	Basic F.A.	(155)	Zeolite	(1328)	Zeolite	(746)
			Illite	(1122)	Illite	(110)
			Basic F.A.	(176)	Basic F.A.	(1.7)
Zn					Zeolite	(10.8)
					Vermiculite	(4.5)
					Basic F.A.	(1.7)
Ni			Zeolite	(13.5)		
			Illite	(5.1)		
			Acidic F.A.	(3.8)		
F	Illite	(175)	Kaolinite	(2.6)	Illite	(9.3)
	Kaolinite	(132)	Illite	(2.2)	Acidic F.A.	(8.7)
	Acidic F.A.	(102)			Kaolinite	(3.5)
Total CN-					Illite	(12.1)
					Vermiculite	(7.6)
					Acidic F.A.	(2.7)
COD	Acidic F.A.	(690)	Illite	(1744)	Vermiculite	(6654)
	Illite	(108)	Acidic F.A.	(1080)	Illite	(4807)
			Vermiculite	(244)	Acidic F.A.	(3818)

* Bracket represents sorbent capacity in micrograms of contaminant removed per gram of sorbent used. After Sheih (1979) and Chan et al. (1979).

† F.A. = fly ash

TYPICAL PHYSICAL AND CHEMICAL PROPERTIES OF COMMONLY USED NATURAL SORBENTS

Sorbent	Bulk density (kg/m^3)	Cation-exchange capacity (meq/100 g)	Anion-exchange (meq/100 g)	Slurry pH	Major mineral species present
Fly ash, acidic	1187	—	—	4-5	Amorphous silicates, hematite, quartz, mullite, free carbon.
Fly ash, basic	1187	—	—	9-10	Calcite, amorphous silicates, quartz, hematite, mullite, free carbon.
Kiln dust	641-890	—	—	9-11	Calcite, quartz, lime (CaO) anhydrite.
Limestone screenings	—	—	—	6-7	Calcite, dolomite.
Clay minerals (soils)	1519			—	Various, e.g., illite.
Kaolinite		5-15	6-20		Can be relatively pure kaolonite.
Vermiculite		100-500	4	—	Can be relatively pure.
Bentonite		100-120	—	—	Smectite, quartz, illite, gypsum, feldspar, kaolinite, calcite.
Zeolite	1543	100-300	—	—	Zeolite (e.g., heulondite, laumonite, stilbite, chabazite, etc.

From: Sheih (1979), Haynes and Kramer (1982), Grim and Guven (1978).

CONCERNS WITH BINDERS

- May themselves contain metals or organics of concern
  - Cement, flyash, etc. can contain mercury, cadmium, etc. in trace quantities
  - Asphalts can contain naphthalenes, other polycyclic organics
- Composition can vary by source

COMPARISON OF REAGENT LEACHING WITH RCRA LIMITS

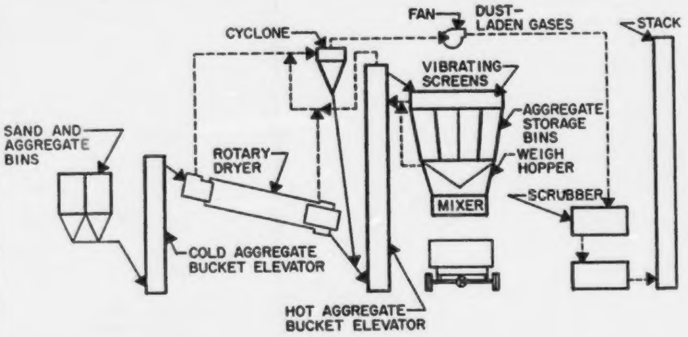
SAMPLE	TEST TYPE	CONCENTRATION (mg/l) IN WASTE OR LEACHATE CADMIUM	CHROMIUM	LEAD	NICKEL
PORTLAND CEMENT	TOTAL	1.11	33.70	57.50	24.90
	EPT	< 0.01	0.26	0.26	0.02
CEMENT KILN DUST (MBI)	TOTAL	3.95	29.00	191.00	11.00
	EPT	< 0.01	0.07	0.49	< 0.01
TYPE C FLYASH	TOTAL	2.97	75.40	221.00	52.50
	EPT	< 0.01	0.14	0.35	0.02
RCRA EPT LIMITS		1.00	5.00	5.00	
DELISTING LIMITS		0.063	0.315	0.315	
DRINKING WATER STANDARDS		0.01	0.05	0.05	

ASPHALT/BITUMEN

- To understand, consider the manufacture of asphaltic concrete

ASPHALT/BITUMEN

- Analogous to asphaltic concrete
- Potential problem with the binder containing organic hazardous constituents
- Organics in the waste tend to dissolve the asphalt/bitumen
- The waste must be "dry"
    - water reduces the cohesion of the solids and asphaltic binder
- The blend is generally temperature sensitive


FAN
DUST-LADEN GASES
STACK
CYCLONE
VIBRATING SCREENS
AGGREGATE STORAGE BINS
WEIGH HOPPER
SAND AND AGGREGATE BINS
ROTARY DRYER
MIXER
SCRUBBER
COLD AGGREGATE BUCKET ELEVATOR
HOT AGGREGATE BUCKET ELEVATOR

Flow Diagram of a Typical Hot-Mix Asphalt Paving Batch Plant

POLYMERIC BINDERS

(Thermoplastic, Thermosetting)

- Used to a limited extent with radioactive wastes
    - blocks of vitrified or otherwise fixed waste coated with a polymer
- Used to treat monomer wastes from polymer production
- Has some potential in treating compatible wastes from Superfund sites - usually as a final treatment
- Very highly waste selective

THERMOPLASTICS

- Melt at higher temperatures
- Usually melted into the waste much as asphaltic binders
- Examples:
  - polyethylene
  - polypropylene

THERMOSETTING PLASTICS

- Monomers react at all temperatures
- The polymer does not melt well - often decomposes at higher temperatures
  Examples:
  - bakelite
  - epoxies
- Produce water on polymerization

COMMERCIAL PROPRIETARY PROCESSES

- Typically use variations of basic concepts

COMMERCIAL WASTE STABILIZATION PROCESSES

Vendor	Process Name	Ingredients	Comments
Chemfix, In	Chemfix	Cement + Soluble Silicates	Probably does not fix most volatile organics
IU Conversion	Sealosafe Stablex	Silicates	Probably does not fix oils, solvents, grease, volatile organics
Dravo Lime	Calcilox	Glassy Slag & Scrubber Sludge	Designed to fix scrubber sludge. probably does not fix most volatile organics
Envirotech (Subsid. of Chemfix)	Envirotech	Cement & Silicates	U.S. Patent 3,837,872
Velsicol	Velsicol	Fly Ash, Scrubber Sludge & Cement	Claims to stabilize organics; not specific
Staborol Corp	Terra-Tite	Cement	Probably does not fix most volatile organics
TRW Systems	--	1. Cement, Plaster & Lime	Does not fix volatile organics may work for organics; very costly

Source: Chemical Waste Management

AIR EMISSIONS FROM S/S PROCESSES

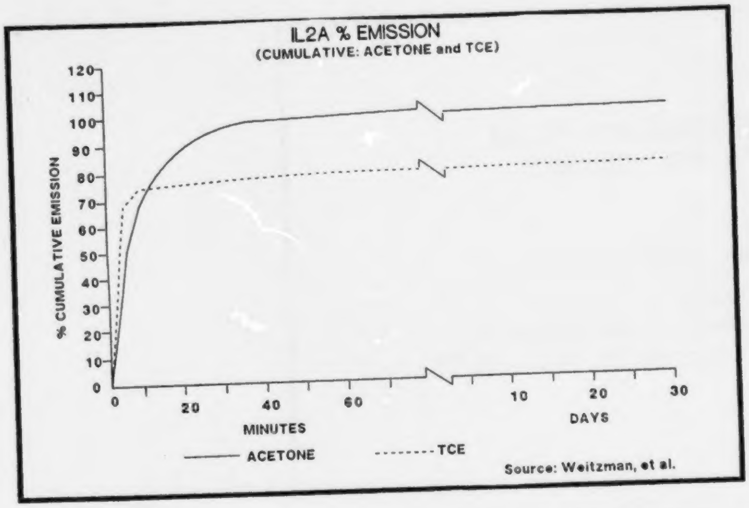
- Particulate
  - usually regulated locally
- Organic vapors
  - regulations in final stages of of development by EPA/OAQPS

S/S OF ORGANIC CONSTITUENTS

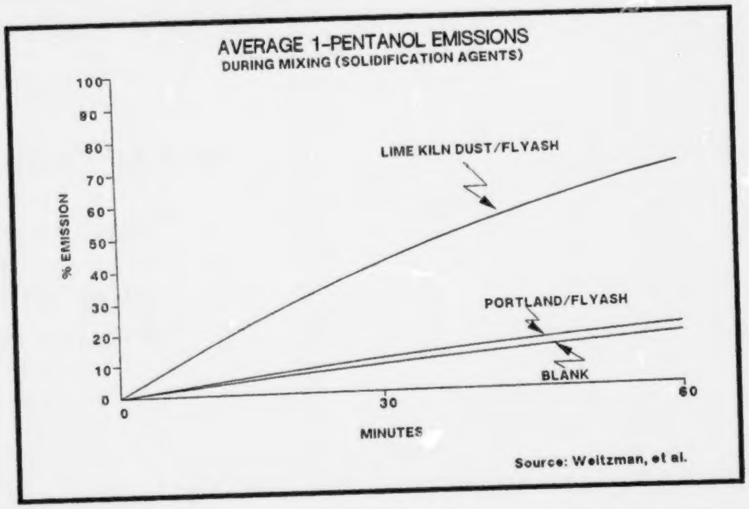
- Rarely react with inorganic binders
- Often interfere with binder setting and inorganic reactions
- Frequently vaporize during S/S

ORGANIC CONSTITUENTS

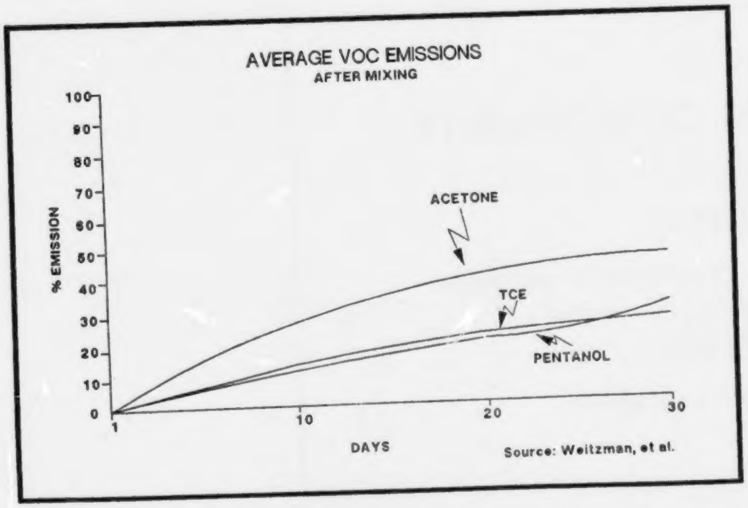
- May volatilize
- Lack of presence in leachate not necessarily indicative of stabilization
- Air pollution problem


IL2A % EMISSION
(CUMULATIVE: ACETONE and TCE)

Source: Weitzman, et al.


AVERAGE 1-PENTANOL EMISSIONS
DURING MIXING (SOLIDIFICATION AGENTS)

Source: Weitzman, et al.


AVERAGE VOC EMISSIONS
AFTER MIXING

Source: Weitzman, et al.

CONCLUSION

Organic Contaminants

- Often volatilize
- Interfere with S/S process
- Dissolve or weaken polymers and bitumen - compatibility critical
- Weaken structural integrity of S/S products
- Increases porosity of product
  - reduces effectiveness of encapsulation

HOW TO DEAL WITH ORGANIC CONSTITUENTS

- Pretreat to remove
  - air strip
  - thermal strip
  - steam strip
  - wet oxidation
- Chemically destroy
  - few organics form stable, nonmobile compounds under mild conditions

Exception: monomers → polymers

(1 of 2)

HOW TO DEAL WITH ORGANIC CONSTITUENTS

- Increase ability of binder to encapsulate organics
  - sodium silicate
  - surfactants

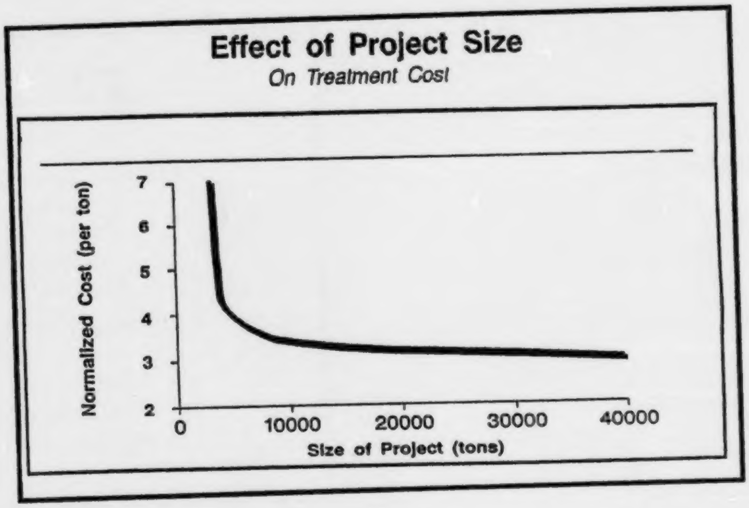
  Does not chemically bind or destroy organic compound
- Mix in enclosed system with collection/control

(2 of 2)

ECONOMICS

100 TPD Operation, All Costs are in $/Ton

Waste	Volume Increase	Chemicals	Processing	Testing	Total Cost Airspace=$20/ton	 Airspace=$80/ton
F006-High Solids (35%)						
PC-Based System	7	14	7	2	44	109
KD-Based System	35	17	9	2	55	136
F006 - Low Solids (10%)						
PC-Based System	10	32	6	2	61	127
KD-Based System	65	32	9	2	76	175


Effect of Project Size

On Treatment Cost

SUMMARY

- Many S/S techniques to choose from
- Need to understand the chemical and physical processes
- Theory is only the first step
- Must then verify and validate theoretical estimates with laboratory and pilot-scale screening tests before selecting alternatives

DESCRIPTION OF VITRIFICATION TECHNOLOGY

SECTION 3

Abstract 3–2
Slides 3–8

VITRIFICATION TECHNOLOGIES

Mr. Jim Hansen
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The Superfund Amendments and Reauthorization Act (SARA) mandated that the Environmental Protection Agency (EPA) give priority to treatment technologies that are: (1) permanent, (2) capable of reducing the toxicity, mobility, and/or volume of hazardous materials, and (3) capable of being performed on-site and in situ. These criteria have proven to be particularly challenging in the difficult area of remediating contaminated soils, sludges, sediments, and process tailings. A group of vitrification technologies hold the potential to satisfy these objectives for many contaminated solids applications. The accompanying figures and following discussion provide a general description of this developing technology area.

Vitrification technologies are those that involve exposure of hazardous materials to molten glass and related process conditions to affect the destruction, removal, and/or permanent immobilization of hazardous contaminants. Vitrification is defined as conversion of such solids into a glass residual form through the application of heat to the point of fusion. The technologies are applicable to use on solids that are capable of forming a molten, vitreous mass, and of producing a glass-like residual product upon cooling. Typically, the residual product is a solid (super-cooled liquid) containing an amorphous mixture of oxides (primarily silica and alumina) with little or no crystallization prosent.

Exposure of contaminants to vitrification processing results in several desirable results: (1) destruction of hazardous organics by pyrolytic decomposition and/or oxidation, (2) removal (partial or full) of low-solubility, high-volatility, high-solubility inorganics in the residual glass product through chemical incorporation and/or encapsulation. Thus, the vitrification processes may be considered as both thermal treatment (destruction) and immobilization processes.

The various vitrification processes similarly produce a glassy residual product resembling natural obsidian in physical and chemical characteristics. The residual product may be made in granular form, cast into containers, or in multi-thousand ton monoliths. Typically the product has excellent structural, weathering, and biotoxicity characteristics, making it suitable for long-term environmental exposure. The residual typically is able to surpass EPA leach testing requirements (e.g., EP-Tox and TCLP), making it a candidate for delisting as a hazardous waste.

There are several different processes that produce a vitrified product. Most of these are performed ex situ, however one is performed in situ. These basic processes are discussed below.

Ex-Situ Vitrification

Ex-situ vitrification technologies include: (1) electric furnace/melter, (2) plasma centrifugal reactor, and (3) slagging kiln/incinerator.

The electric furnace/melter class includes processes that utilize a ceramic-lined, steel-shelled melter, to contain the molten glass and waste materials to be melted. Some of these processes utilize equipment quite similar to electric glass furnaces that have widespread use for the manufacture of glass products (e.g., bottles, plate products). Such melters involve placement of waste materials and glass batch chemicals directly on the surface of a molten glass bath. The majority of melting occurs at the waste/molten glass interface as heat is transferred from the molten glass. As such waste is heated, organics and inorganic volatiles are evolved and either pyrolyzed or oxidized prior to off-gas treatment to ensure safe air emissions.

Another class of melters involve feeding mechanisms that introduce the waste materials below the molten glass surface. Such method of introduction results in the pyrolysis of organic contaminants within the molten glass, followed by evolution of pyrolyzed off-gases to the space above the glass surface and thence to the off-gas treatment system. Both classes of melters result in the incorporation of nonvaporizable inorganics into the molten glass.

Periodically, the electric melters must be tapped to remove the accumulated glass product. The molten glass may be cast directly into containers. Another alternate utilizes a water bath to produce a granular residual product. The containerized or loose residual product must then be disposed.

The plasma centrifugal reactor varies significantly from the melter/furnace concept. In the plasma reactor, prepared waste materials are fed into a rotating reactor well in which a transferred-arc plasma torch is operating. The plasma torch, which is capable of temperatures exceeding 10,000°C, heats the waste material beyond the point of melting to about (typically) 1,600°C. The melted material is allowed to fall into a slag chamber where it is collected in a container.

Organics and other volatiles emitted during the plasma heating are passed to a secondary combustion chamber into which an oxidizing gas is added. The resulting off-gases are then transferred to an off-gas treatment system to ensure safe air emissions. The containerized slag must eventually be disposed.

Last, solids may be vitrified in rotary kilns and incineration equipment that is operated in a slagging mode. Large kilns are able to accommodate whole drums and mixed solids with little or no pretreatment being required.

Such large facilities are typically stationary as opposed to mobile, on-site facilities. In these facilities, the vitrified product is removed from the exit end of the kiln; it may be cast into containers or granulated as done for the other technologies mentioned above.

Being ex-situ processes, it is necessary that application of each of the above three classes of processes involve excavation, and possible pretreatment of waste materials as required to allowing feeding and proper treatment. In each case the residual product must be disposed; however, the difficulties of such disposal may be minimized if the residual product is of sufficient quality to be delisted.

In-Situ Vitrification

There is one vitrification technology, designated ISV for in-situ vitrification, which brings the benefits of the molten glass exposure and high quality glass residual product to the in-situ application area. The ISV process system has been developed and demonstrated through large-scale; wastes treated include a variety of hazardous chemical, radioactive, and mixed (hazardous chemical and radioactive) wastes.

The ISV process electrically melts inorganic materials (e.g., soil) for the purpose of thermochemical treating free and/or containerized contaminants present within the treatment volume. Most ISV applications involve melting of natural soils; however, other naturally occurring or process residual inorganics (e.g., sludge, tailings, sediments), or process chemicals may be utilized. When used to treat contaminated soil, the process simultaneously destroys and/or removes organic contaminants while chemically incorporating (immobilizing) inorganic contaminants into a chemically inert, stable glass and crystalline residual product.

An array (usually square) of four electrodes is placed to the desired treatment depth in the volume to be treated. As electric potential is applied between the electrodes, current flows through the starter path, heating it and the adjacent soil to temperatures above 1600°C, which is well above typical soil fusion temperatures. Upon melting, typical soils become quite electrically conductive; thus the molten mass becomes the primary conductor and heat transfer medium allowing the process to continue beyond startup. Continued application of electric energy causes the molten volume to grow downward and outward encompassing the desired treatment volume. The rate of melt advance is in the 1 to 2 in/hr range. Individual settings (i.e., the melt involved with a single placement of electrodes) may grow to encompass a total melt mass of up to 1000 ton and a maximum width of about 30 ft. Single setting depths as great as 30 ft are considered possible with the existing large-scale ISV equipment. Adjacent settings are positioned to fuse to each other and to completely process the desired volume at a site.

The molten soil mass is typically in the 1600 to 2000°C temperature range; specific temperatures are dependent on the overall chemistry of the melt. Within the melt, a vigorous, chemically reducing environment is typical. Because soil typically has low thermal conductivity, a very steep thermal gradient (i.e., 150-250°C/in) precedes the advancing melt surfaces. Typically, the 100°C isotherm is less than 1 ft away from the molten mass itself. The soil volume between the 100°C isotherm and the melt is termed the dry zone; this zone has maximum vapor permeability as it exists without water present in the liquid state.

The large-scale ISV system melts soil at a rate of 4 to 6 ton/hr. Since the void volume present in particulate materials (e.g., 20-40% for typical soils) is removed during processing, a corresponding volume reduction occurs. Also, since some of the materials present in the soil are removed as gases and vapors during processing (e.g., humus, organic contaminants), further volume reduction occurs. The volume reduction creates a subsidence volume above the melt and an angle of repose in the soil adjacent to the melt. Upon cooling, an obsidian-like vitrified monolith results (silicate glass and microcrystalline structure); this product possesses excellent structural and environmental properties.

The process utilizes a mobile, on-site equipment system. Electric power is usually taken from a utility distribution system at transmission voltages of 12,500 or 13,800 volts; alternatively the power may be generated on site by a diesel generator. The 3-phase power is supplied to a special multiple-tap transformer (Scott Tee) that converts the power to 2-phase and transforms it to the voltage levels needed throughout the processing. The electrical supply system utilizes an isolated ground circuit which provides appropriate operational safety.

Flow of air through the hood is controlled to maintain a negative pressure (0.5 to 1.0 in H_2O). An ample supply of air provides excess oxygen for combustion of pyrolysis products and organic vapors, if any evolve from the treatment volume. The off-gases, combustion products and air are drawn from the hood (by induced draft blower) into the off-gas treatment system which utilizes the following unit processes to ensure compliant air emissions: (1) quenching, (2) pH controlled scrubbing, (3) dewatering (mist elimination), (4) heating (for dewpoint control), (5) particulate filtration, and (6) activated carbon adsorption. A self-contained glycol cooling system is utilized to cool the quenching/scrubbing solution; this avoids the need for a constant on-site water supply. The amount of moisture present in the exhaust air stream is controlled to accommodate the moisture that is removed form the treatment volume during processing.

A backup off-gas treatment system is provided to accommodate the possibility of power failure. The backup system employs a diesel-powered generator, blower, mist cooler, filter and activated carbon column. The backup system is capable of removing and treating off-gases during a power outage or during the initial cooling time at completion of a setting.

The disposition of contaminants during ISV processing is dependent upon many variables, the most important of which may be grouped into the categories of: (1) pre-melt soil properties, (2) contaminant quantities and properties, and (3) molten zone properties and conditions. Disposition of contaminants depends on the response of the contaminants to the process conditions; individual contaminants may respond to the system of processing variables in several ways, including: (1) change of state, (2) physical movement, and (3) physical/chemical reaction.

There are five (5) basic types of mechanisms that relate to movement responses of contaminants during processing; including: (1) capillary action, (2) concentration-based diffusion, (3) thermally induced vapor transport, (4) melt convective flow, and (5) liquid/vapor adsorption on soil. The combination of processing conditions and responses of contaminants may result in five (5) basic dispositions of the contaminants, including: (1) destruction of compounds, (2) physical removal from the treatment volume to the off-gas treatment system, (3) chemical incorporation into the vitrified product, (4) physical encapsulation within the vitrified product, and (5) continued existence as a minor residual within the treatment zone.

Certain response types and ultimate dispositions are dominant for various classes of contaminants. As organic vapors distribute themselves throughout the void space adjacent to the melt, they increase in temperature to their pyrolysis temperature, where they break down into successively smaller chains of molecules and eventually reach the state of elemental or diatomic gases. Upon pyrolysis, the concentration of the original compound vapor is thereby diminished, resulting in a continued concentration gradient of the original vapor toward the pyrolysis isotherm (i.e., toward the melt). For hazardous organic contaminants, pyrolytic destruction is the dominant disposition; destruction efficiencies in the soil column (prior to off-gas treatment) on the order of 99.9 to 99.995 wt% have resulted from ISV tests involving hazardous organics. The level of destruction can be increased by recycling the organics recovered in the off-gas system to a subsequent ISV setting. Chemical incorporation is the dominant disposition of hazardous inorganic elements (e.g., heavy metals). The ISV silicate glass is very durable relative to environmental exposure and will hold a wide variety of materials in nonleachable form. In addition to chemical incorporation, some amount of volatile or semi-volatile inorganics (e.g., Pb, Hg) may be removed from the treatment volume and recovered in the off-gas treatment system; they may then be disposed by an alternative means or be recycled to a subsequent ISV melt for further disposition by chemical incorporation.

The contaminated soil subject to ISV treatment may be configured in numerous ways for processing. The material may be processed in situ where is presently is, or it may be staged above or below grade for treatment. Special cases also include containerized treatment, stacked settings for deep contamination, continuous feeding arrangements for high volume reduction material, and special conditions for vitrifying underground tanks.

The ISV process can also accommodate significant quantities of inclusions in the treatment volume. Inclusions are defined as highly concentrated contaminant layers, void volumes, containers, metal scrap, general refuse, demolition debris, rock, or other non-homogenous materials or conditions within the waste volume.

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VITRIFICATION TECHNOLOGIES

DEFINITIONS

GLASS - A solid (super-cooled liquid) containing an amorphous mixture of oxides (primarily silica) with little or no crystallization present

VITRIFY - To convert solids into glass through heat fusion

TREATMENT MECHANISMS

1) Destruction of Organics
   - Pyrolytic decomposition
   - Oxidation
2) Removal of Inorganics (partial to complete for low-solubility, high-volatility materials)
3) Immobilization of Inorganics in Residual Glass Product
   - Chemical incorporation
   - Encapsulation

TYPICAL RESIDUAL PROPERTIES

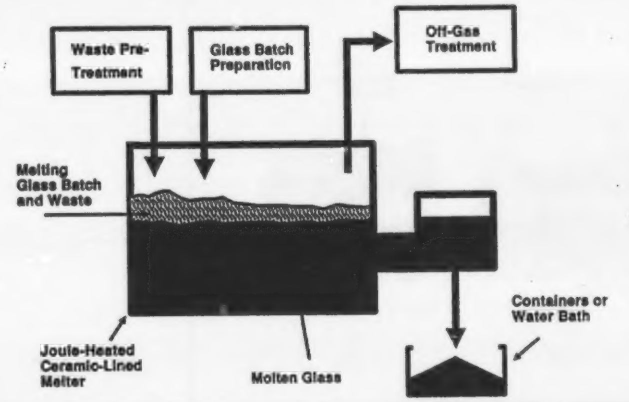
Composition:	Analogous to natural obsidian
Strength:	10X concrete
Volume Reduction:	20-40 %
Toxicity Reduction:	Organics are removed/destroyed Inorganic-bearing residual found to have acceptable biotoxicity (EPA)
Mobility Reduction:	Surpasses EP-Tox, TCLP
Wet/Dry Cycling:	Unaffected
Freeze/Thaw Cycling:	Unaffected
Life Expectancy:	DOE glass waste form research indicates geologic time period

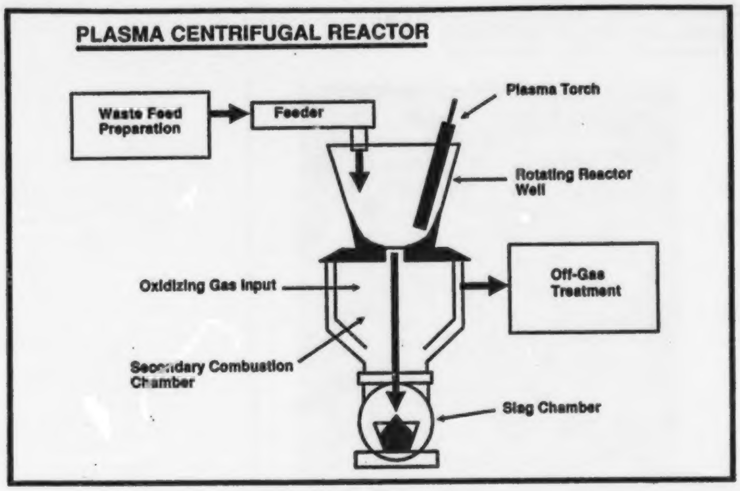
VITRIFICATION TECHNOLOGIES

ALTERNATIVE VITRIFICATION TECHNOLOGIES

- **Electric Furnace/Melter**
- **Plasma Reactor**
- **Slagging Kiln/Incinerator**
- **In Situ Vitrification (ISV)**

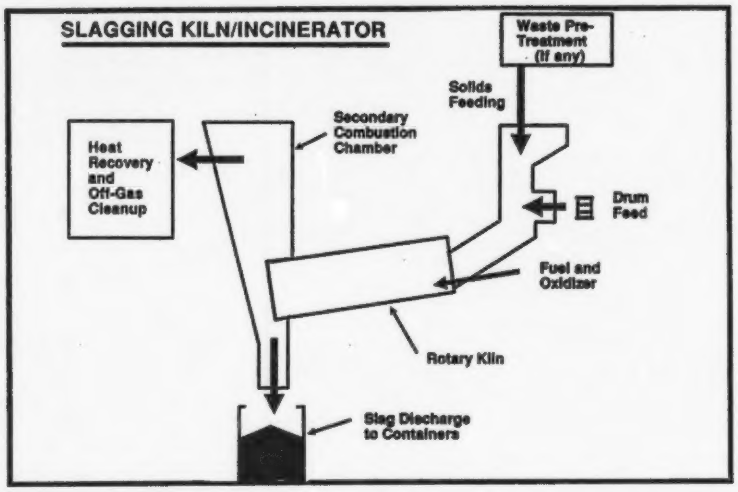
ELECTRIC MELTER/FURNACE


Waste Pre-Treatment
Glass Batch Preparation
Off-Gas Treatment
Melting Glass Batch and Waste
Containers or Water Bath
Joule-Heated Ceramic-Lined Melter
Molten Glass



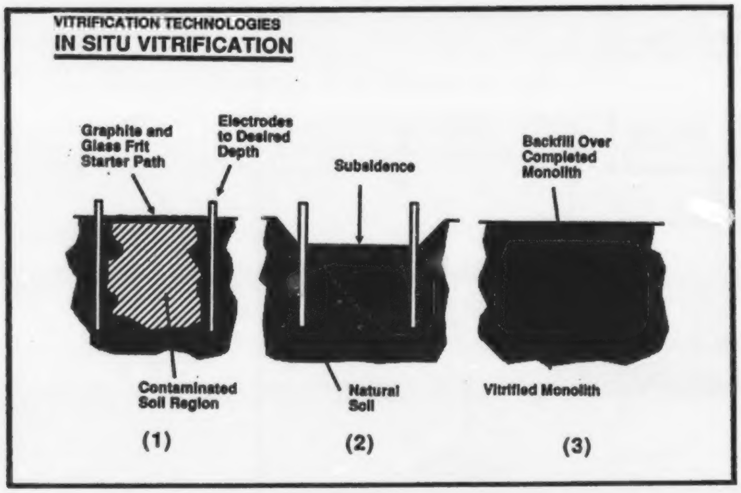
PLASMA CENTRIFUGAL REACTOR

Waste Feed Preparation
Feeder
Plasma Torch
Rotating Reactor Well
Off-Gas Treatment
Oxidizing Gas Input
Secondary Combustion Chamber
Slag Chamber



SLAGGING KILN/INCINERATOR

Waste Pre-Treatment (If any)
Solids Feeding
Secondary Combustion Chamber
Heat Recovery and Off-Gas Cleanup
Drum Feed
Fuel and Oxidizer
Rotary Kiln
Slag Discharge to Containers



VITRIFICATION TECHNOLOGIES
IN SITU VITRIFICATION

Graphite and Glass Frit Starter Path
Electrodes to Desired Depth
Subsidence
Backfill Over Completed Monolith
Contaminated Soil Region
Natural Soil
Vitrified Monolith
(1)
(2)
(3)

VITRIFICATION TECHNOLOGIES

BASIC COMPARISON OF TYPES (Page 1 of 2)

	APPLICABLE MATERIALS	WHERE PERFORMED	TYPICAL OPERATING TEMPERATURE	ORGANIC DESTRUCTION MECHANISM
ELECTRIC FURNACE/ MELTER	Dry/Wet Solids	Mobile, On-Site, Ex-Situ	11-1,200 C	Pyrolysis or Oxidation
PLASMA REACTOR	Dry/Wet Solids	Mobile, On-Site, Ex-Situ	1,600 C (glass) 10,000 C (plasma)	Oxidation
SLAGGING KILN/ INCINERATOR	Dry/Wet Solids, Containers (some only)	Transportable, On-Site, Ex-Situ	11-1,500 C	Oxidation
IN SITU VITRIFICATION	Dry/Wet Solids, Containers, Rubble	Mobile, On-Site, In Situ	16-2,000 C	Pyrolysis

VITRIFICATION TECHNOLOGIES

BASIC COMPARISON OF TYPES (Page 2 of 2)

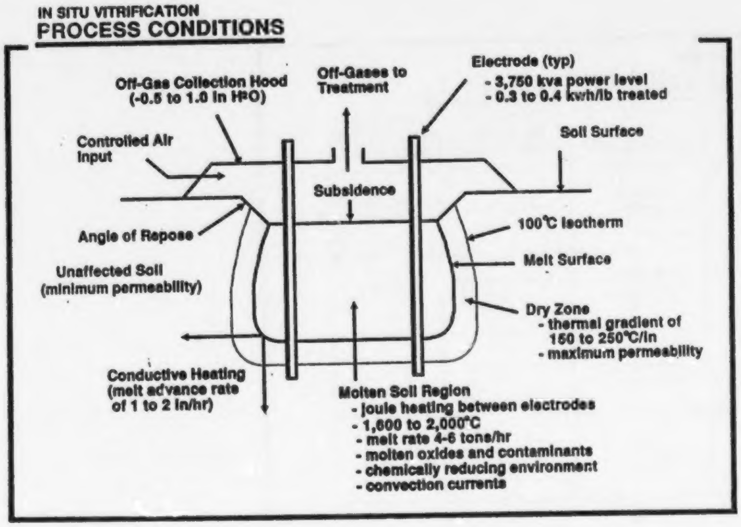
	TYPICAL THROUGHPUT RATE	PRE-TREAT REQUIRE-MENTS	NATURE OF RESIDUAL	POST-TREAT REQUIRE-MENTS
ELECTRIC FURNACE/ MELTER	0.5-3 tph	Excavate, Sort, Particle Size Screening	Solid-filled Containers or Granular	Disposal of Residual
PLASMA REACTOR	0.1-0.3 tph	Excavate, Sort, Particle Size Screening	Slag in Container	Disposal of Residual
SLAGGING KILN/ INCINERATOR	6 tph 30 drums/h	Excavate (some sort and particle size)	Slag in Container	Disposal of Residual
IN SITU VITRIFICATION	4-6 tph	None	Contiguous Monolith	Backfill Subsidence

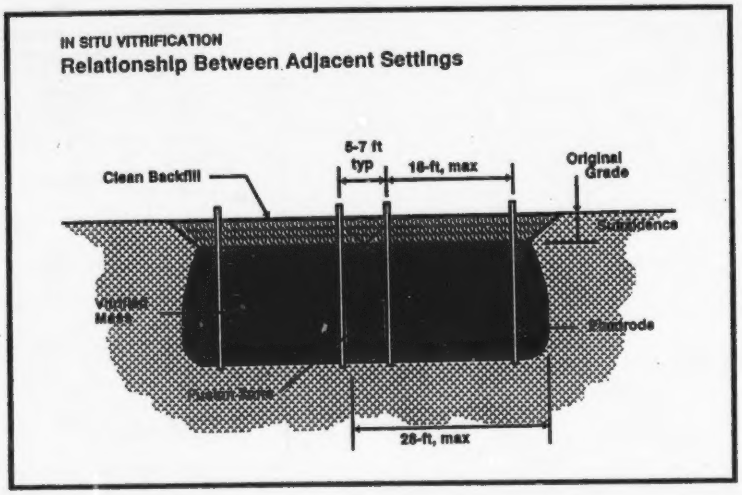
IN SITU VITRIFICATION

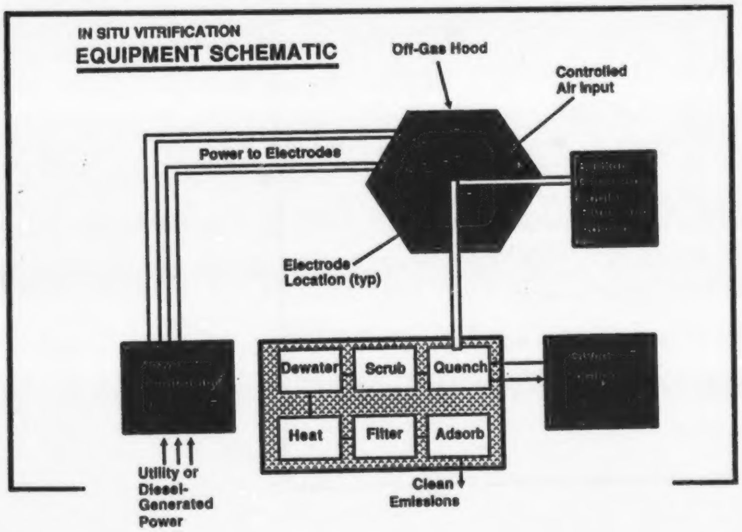
TECHNOLOGY DEFINITION

In situ electric melting of staged or as-deposited contaminated solids (e.g., soil, sediment, sludge, tailings, various inclusions) for purposes of:

1) organic destruction/removal
2) inorganic immobilization/removal
3) barrier wall formation


IN SITU VITRIFICATION
PROCESS CONDITIONS
Off-Gas Collection Hood (-0.5 to 1.0 in H_2O)
Off-Gases to Treatment
Electrode (typ)
- 3,750 kva power level
- 0.3 to 0.4 kwh/lb treated
Controlled Air Input
Soil Surface
Subsidence
Angle of Repose
100°C Isotherm
Melt Surface
Unaffected Soil (minimum permeability)
Dry Zone
- thermal gradient of 150 to 250°C/in
- maximum permeability
Conductive Heating (melt advance rate of 1 to 2 in/hr)
Molten Soil Region
- joule heating between electrodes
- 1,600 to 2,000°C
- melt rate 4-6 tons/hr
- molten oxides and contaminants
- chemically reducing environment
- convection currents


IN SITU VITRIFICATION
Relationship Between Adjacent Settings
Clean Backfill
5-7 ft typ
18-ft, max
Original Grade
Subsidence
Vitrified Mass
Electrode
Fusion Zone
28-ft, max


IN SITU VITRIFICATION
EQUIPMENT SCHEMATIC
Off-Gas Hood
Controlled Air Input
Power to Electrodes
Electrode Location (typ)
Dewater
Scrub
Quench
Heat
Filter
Adsorb
Utility or Diesel-Generated Power
Clean Emissions

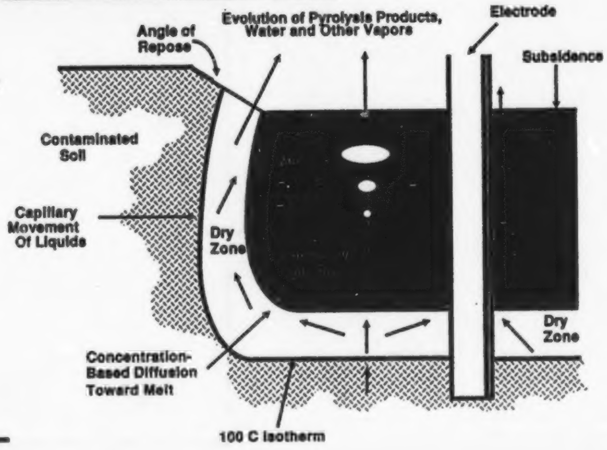
IN SITU VITRIFICATION

CONTAMINANT MOVEMENT MECHANISMS DURING ISV PROCESSING

- Capillary Action - movement of liquids toward dry zone
- Molecular Diffusion - concentration-based movement of vapors toward melt
- Carrier-Gas Transport - stripping of vapors by water vapor
- Density Differential - movement of vapors into melt and toward surface
- Pressure Differential - vapor flow toward negative surface pressure
- Convection - thermally induced circulation within melt

IN SITU VITRIFICATION

MOVEMENT OF CONTAMINANTS


Evolution of Pyrolysis Products, Water and Other Vapors
Electrode
Angle of Repose
Subsidence
Contaminated Soil
Capillary Movement Of Liquids
Dry Zone
Dry Zone
Concentration-Based Diffusion Toward Melt
100 C Isotherm

IN SITU VITRIFICATION

POSSIBLE CONTAMINANT DISPOSITIONS

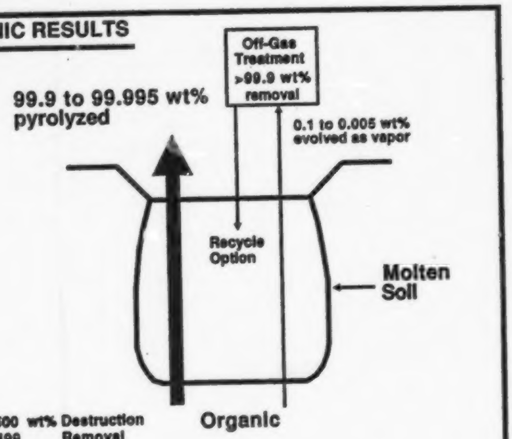
- Destruction (chemical/thermal)
- Removal to off-gas treatment
- Chemical incorporation in glass residual
- Physical encapsulation in glass residual
- Continued existence as adjacent residual

IN SITU VITRIFICATION

PRIMARY FACTORS AFFECTING CONTAMINANT DISPOSITION

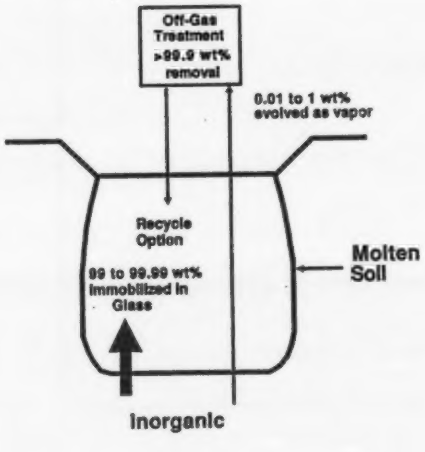
- Contaminant physical/chemical properties
- Melt chemistry
- Melt temperature
- Dwell time (viscosity, depth)
- Adjacent soil properties
- Soil moisture content
- Degree of overmelting

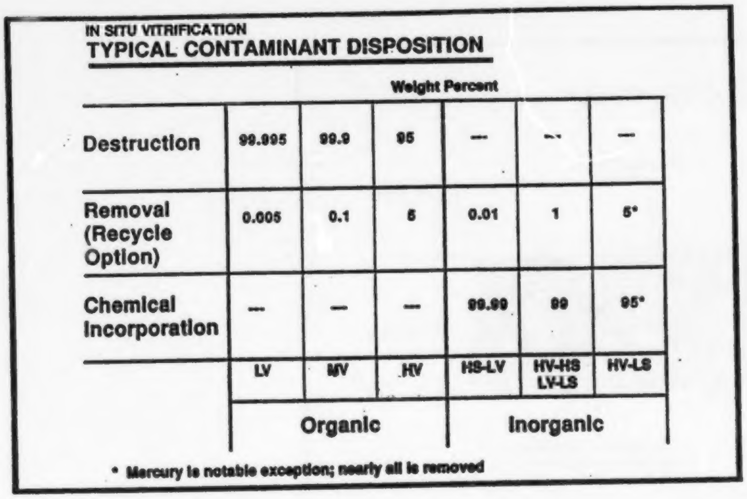
TYPICAL ORGANIC RESULTS


Off-Gas Treatment >99.9 wt% removal
99.9 to 99.995 wt% pyrolyzed
0.1 to 0.005 wt% evolved as vapor
Recycle Option
Molten Soil
Organic

99.9000 to 99.99500 wt% Destruction
> 0.0999 to > 0.00499 Removal
> 99.9999 to > 99.99999 Total DRE

Typical Inorganic Results


Off-Gas Treatment >99.9 wt% removal
0.01 to 1 wt% evolved as vapor
Recycle Option
99 to 99.99 wt% Immobilized in Glass
Molten Soil
Inorganic



IN SITU VITRIFICATION

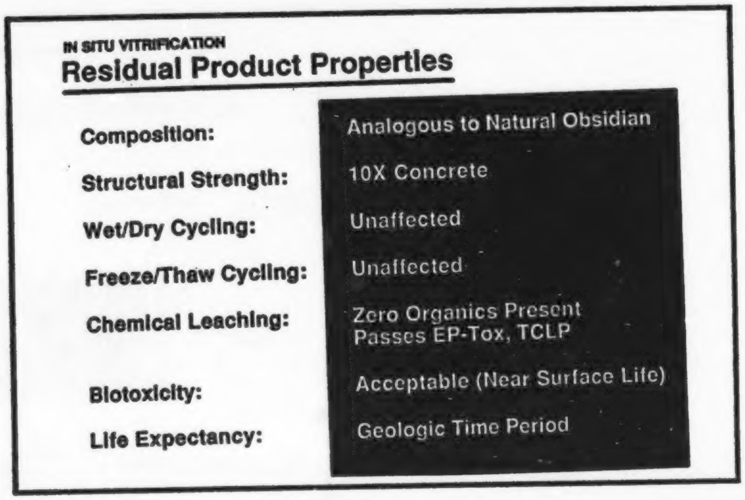
TYPICAL CONTAMINANT DISPOSITION

Weight Percent

	Organic			Inorganic		
	LV	MV	HV	HS-LV	HV-HS LV-LS	HV-LS
Destruction	99.995	99.9	95	—	—	—
Removal (Recycle Option)	0.005	0.1	5	0.01	1	5*
Chemical Incorporation	—	—	—	99.99	99	95*

* Mercury is notable exception; nearly all is removed

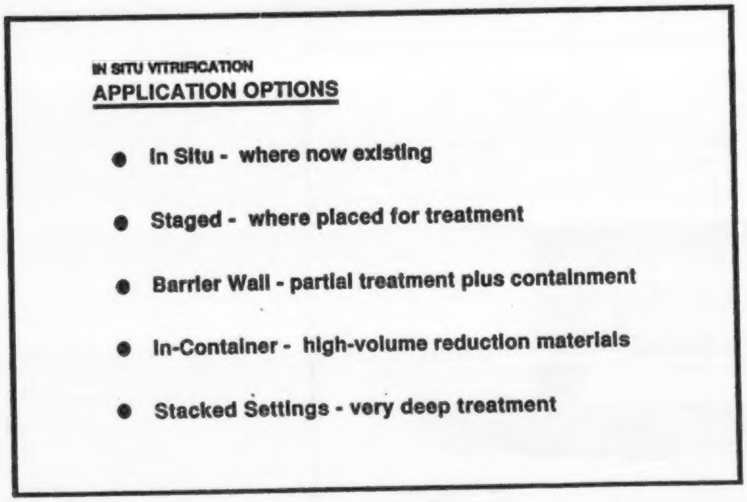
Note:
L = Low
M = Medium
H = High
V = Volatiles
S = Solubility



IN SITU VITRIFICATION

Residual Product Properties

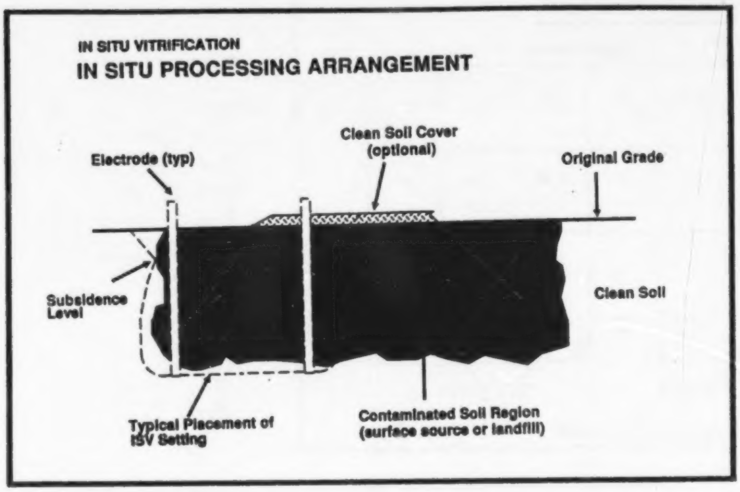
Composition:	Analogous to Natural Obsidian
Structural Strength:	10X Concrete
Wet/Dry Cycling:	Unaffected
Freeze/Thaw Cycling:	Unaffected
Chemical Leaching:	Zero Organics Present Passes EP-Tox, TCLP
Biotoxicity:	Acceptable (Near Surface Life)
Life Expectancy:	Geologic Time Period

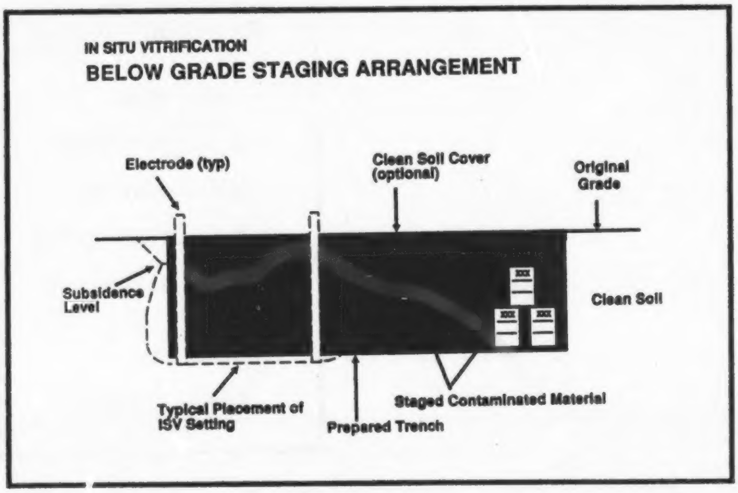


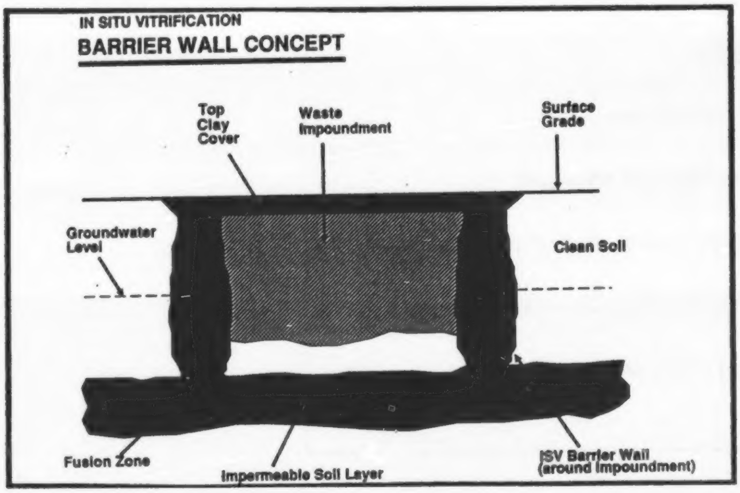
IN SITU VITRIFICATION

APPLICATION OPTIONS

- **In Situ - where now existing**
- **Staged - where placed for treatment**
- **Barrier Wall - partial treatment plus containment**
- **In-Container - high-volume reduction materials**
- **Stacked Settings - very deep treatment**

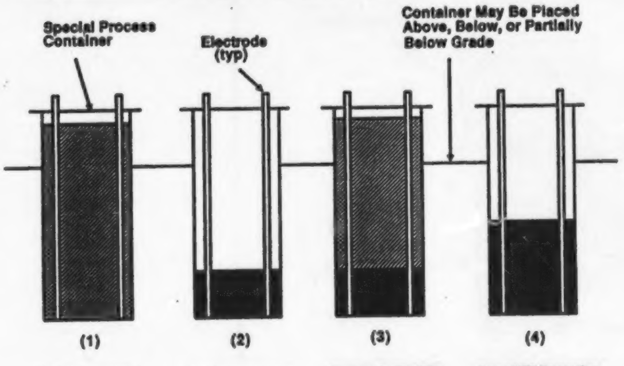

IN SITU VITRIFICATION
IN SITU PROCESSING ARRANGEMENT
Electrode (typ)
Clean Soil Cover (optional)
Original Grade
Subsidence Level
Clean Soil
Typical Placement of ISV Setting
Contaminated Soil Region (surface source or landfill)


IN SITU VITRIFICATION
BELOW GRADE STAGING ARRANGEMENT
Electrode (typ)
Clean Soil Cover (optional)
Original Grade
Subsidence Level
Clean Soil
Typical Placement of ISV Setting
Prepared Trench
Staged Contaminated Material

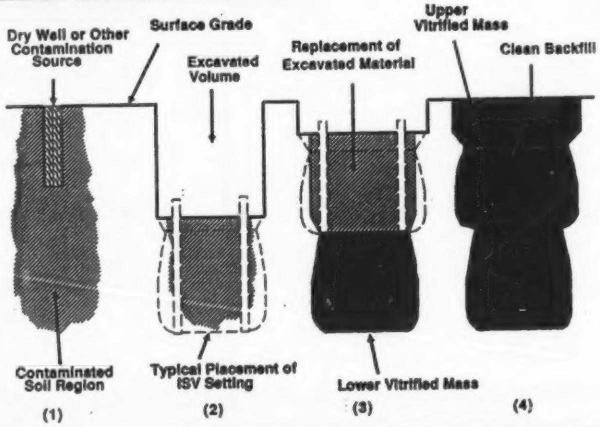

IN SITU VITRIFICATION
BARRIER WALL CONCEPT
Top Clay Cover
Waste Impoundment
Surface Grade
Groundwater Level
Clean Soil
Fusion Zone
Impermeable Soil Layer
ISV Barrier Wall (around impoundment)

IN SITU VITRIFICATION

IN-CONTAINER PROCESSING CONCEPT


Special Process Container
Electrode (typ)
Container May Be Placed Above, Below, or Partially Below Grade
(1)
(2)
(3)
(4)
Container Filled With High Volume Reduction Contaminated Material
First ISV Processing Complete
Container Refilled With Contaminated Material
Second ISV Processing Complete (process may be continued)

STACKED SETTING CONCEPT


Dry Well or Other Contamination Source
Surface Grade
Excavated Volume
Replacement of Excavated Material
Upper Vitrified Mass
Clean Backfill
Contaminated Soil Region
Typical Placement of ISV Setting
Lower Vitrified Mass
(1)
(2)
(3)
(4)

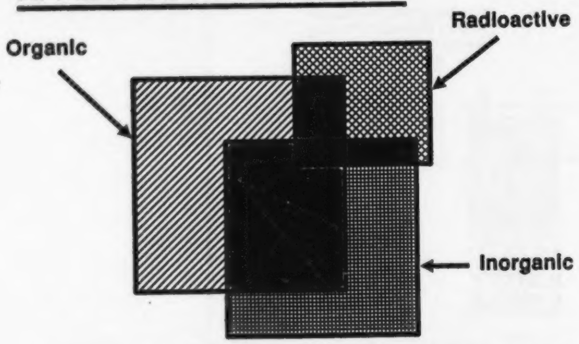
IN SITU VITRIFICATION

BASIC APPLICATION CONSIDERATIONS

- Contaminants (type, concentration, depth, required cleanup levels)
- Solids (type, properties, moisture content, stratigraphy)
- Ground water (location, recharge rate)
- Electricity (availability, price)
- Inclusions (physical/chemical definition)
- Structures (above/below surface)
- Volume (depth, area arrangement)

VITRIFICATION TECHNOLOGIES

APPLICABLE WASTE TYPES


Radioactive
Organic
Inorganic

Vitrification is Applicable to Mixtures of All Types

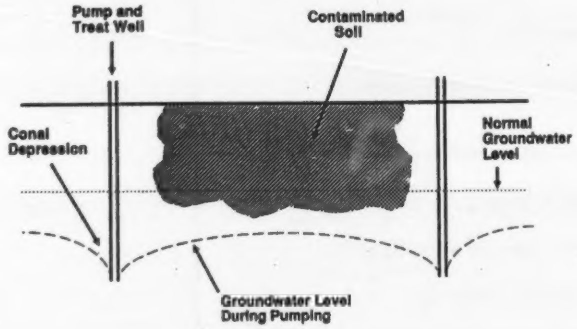
IN SITU VITRIFICATION

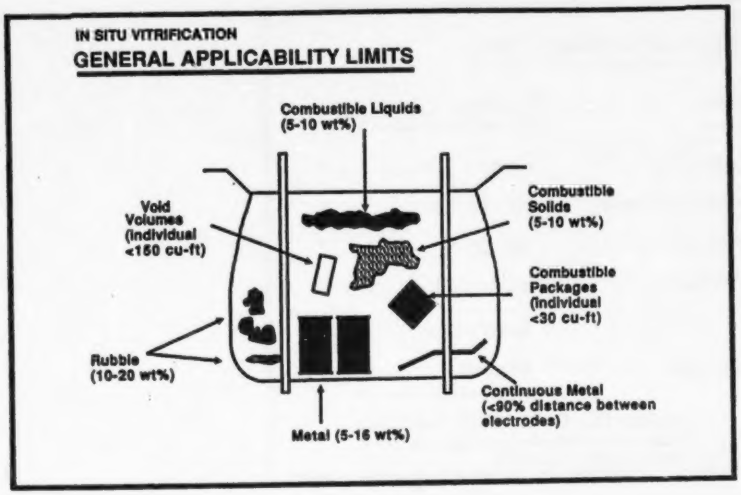
WATER CONSIDERATIONS

- Process removes water
- Fully saturated soils, slurries may be processed
- Energy for water removal increases cost
- In-aquifer processing dependent on recharge rate
- In-aquifer options:
  1) Lower water table
  2) Reduce recharge rate

IN SITU VITRIFICATION

PUMPING TO LOWER WATER TABLE

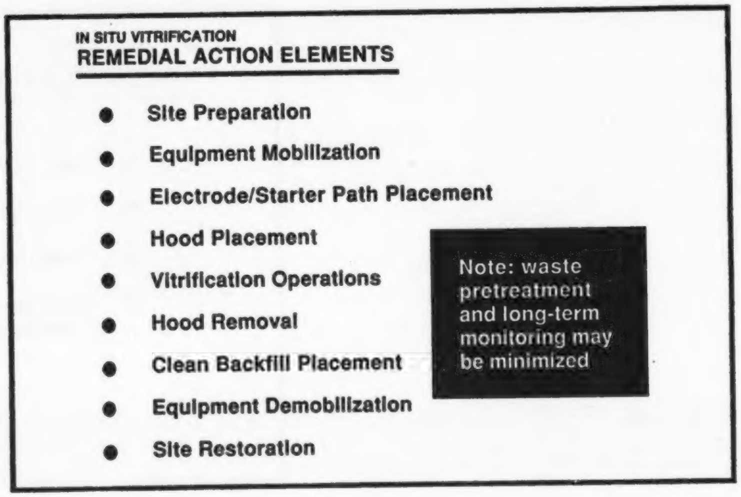

Pump and Treat Well
Contaminated Soil
Conal Depression
Normal Groundwater Level
Groundwater Level During Pumping



IN SITU VITRIFICATION

GENERAL APPLICABILITY LIMITS

Combustible Liquids (5-10 wt%)
Void Volumes (individual <150 cu-ft)
Combustible Solids (5-10 wt%)
Combustible Packages (individual <30 cu-ft)
Rubble (10-20 wt%)
Continuous Metal (<90% distance between electrodes)
Metal (5-16 wt%)

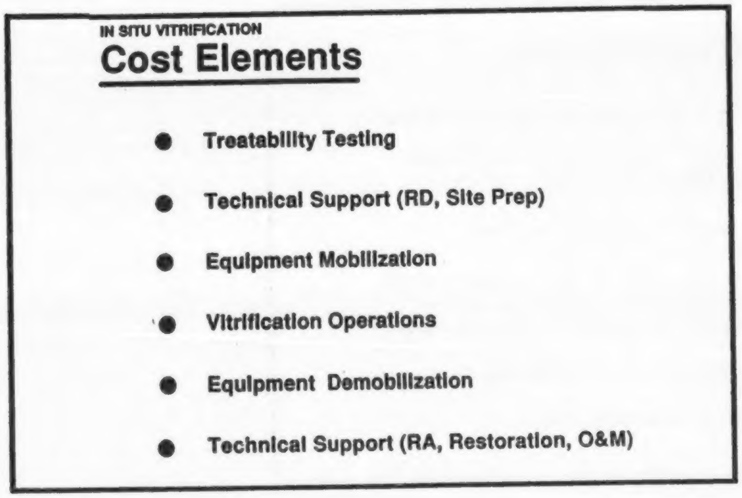


IN SITU VITRIFICATION

REMEDIAL ACTION ELEMENTS

- Site Preparation
- Equipment Mobilization
- Electrode/Starter Path Placement
- Hood Placement
- Vitrification Operations
- Hood Removal
- Clean Backfill Placement
- Equipment Demobilization
- Site Restoration

Note: waste pretreatment and long-term monitoring may be minimized



IN SITU VITRIFICATION

Cost Elements

- Treatability Testing
- Technical Support (RD, Site Prep)
- Equipment Mobilization
- Vitrification Operations
- Equipment Demobilization
- Technical Support (RA, Restoration, O&M)

IN SITU VITRIFICATION

Major Variables Affecting Cost

Variable	Typical Case
Unit Price of Electricity	$0.03 - .06/kwh
Soil/Waste Moisture Content	10 - 20 wt%
Depth of Processing	10 - 20 ft
Size (Volume of Site)	3 - 50,000 cy
Soil Type	Sand - Clay
Staging Requirements	Minimal

Typical ISV Cost: $250 - 350/ton
(excludes treatability testing, technical support, mobilization/demobilization)

Source: Geosafe Corp.

IN SITU VITRIFICATION

POWER REQUIREMENTS

- 12.5 or 13.8 kva supply
- Total of 4 Mw available
- Consumes 0.3 to 0.4 kwh/lb treated
- May be diesel-generated if not readily available from local utility

IN SITU VITRIFICATION

TECHNOLOGY BACKGROUND/STATUS

- Originally DOE technology (transuranic oriented)
- Developed/demonstrated through large-scale ($15m since 1980)
- Commercial capability established 1989
- SITE Program evaluation at site selection stage
- Numerous Superfund treatability tests completed
- Numerous RI/FS and RCRA CA studies evaluating
- Superfund procurements in process

PHYSICAL TESTING METHODS FOR DETERMINING EFFECTIVENESS OF S/S PROCESSES

SECTION 4

Abstract 4–2
Slides 4–5

PHYSICAL TESTING METHODS FOR DETERMINING THE EFFECTIVENESS OF S/S PROCESSES

Mr. Peter Hannak
CH2M Hill
Waterloo, Ontario

Mr. Richard McCandless
UC/Center Hill Lab
Cincinnati, Ohio

Physical and Engineering testing methods are applicable to:

- untreated S/S wastes
- site characterization (excavation and disposal)
- treatability studies
- S/S process control
- S/S product evaluation

Results of tests may be used directly for the assessment of the waste. However, properties such as porosity and volume increases are calculated from the results of appropriate tests.

The physical properties of S/S wastes provide the means to:

- establish treatment objectives and to measure the effectiveness of contaminant immobilization
- compare a variety of treatment processes and enable the selection of suitable processes
- evaluate economics of the S/S process and minimize associated cost
- assure safety of operations and product
- minimize any air or liquid emissions during the processing phase

The physical/engineering test results are to be used to supplement the results of chemical testing, therefore interpretation of S/S process evaluation should include both groups of tests.

The physical/engineering test may be grouped into two categories as to the type of information which can be obtained.

- characterization of intrinsic waste properties
- site-specific information

The full understanding of the behavior of the waste at a site, can only be described if both types of information are available. The testing methods that are applicable to the untreated wastes includes methods related to:

- liquid solid classification
- particle size analysis
- moisture content
- bulk density
- permeability and
- strength

The inter-relationship of these tests and purpose of their application to S/S process evaluation are discussed in the presentation.

Further discussion of specific methods include tests of regulatory importance (Paint Filter/Liquid Release tests), tests used as guidance (Unconfined Compressive Strength Tests) and tests required for site/waste characterization, including field permeability.

Approach and equipment are described to provide application guidance for the audience. The signification and limitations of the individual methods are presented along with the applicable literature and standard references. The scientific background of complex tests, such as permeability measurement, is presented in the format of charts and equations where necessary.

The function of physical/engineering tests for process characterization are also discussed. These functions include the use of tests for process control and treatability studies on bench and pilot scale.

Mechanisms of interferences affecting the final physical/engineering properties of the S/S wastes are detailed as follows:

- adsorption
- complexion
- precipitation
- nucleation

The inter-relationships of physical/engineering tests performed on the final product are also presented. The applicable tests include:

- bulk density
- specific gravity
- moisture content
- permeability
- weathering resistance
- unconfined compression

These tests are presented in detail including the modifications of procedures to make these tests suitable to S/S wastes.

The application of specific tests under development will expand the understanding of the process and assist in the evaluation of the quality of the S/S waste products. Specific examples include; microcharacterization and dissolution tests.

A discussion concerning the range and inter-relationship/trend of properties is provided. The support for the discussion is based on a series of unpublished experiment results from an international cooperative study carried out with the participation of the industry. This study characterized waste streams from a variety of sources including:

- Synthetic wastes
- Wood preservative wastes
- Dredge spoil
- Electroplating wastes

The characterization of waste stabilized by commercial processes provides a cross-section of S/S waste properties outlined in this presentation.

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SCOPE

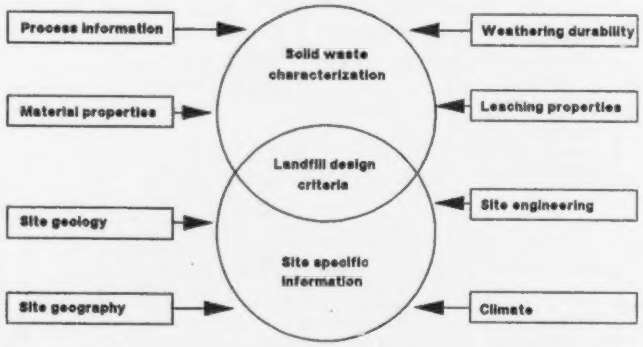
- Untreated waste/site
- Treatability studies
- (Process)
- S/S wastes

Does not include soil testing

SIGNIFICANCE OF WASTE CHARACTERIZATION

- Establish treatment objectives
- Select the best treatment option
- Minimize treatment cost
- Assure safety of operations
- Minimize by-products and emissions

INFORMATION REQUIREMENTS FOR SOLID WASTE LANDFILL DESIGN



Process information

Material properties

Site geology

Site geography

Solid waste characterization

Landfill design criteria

Site specific information

Weathering durability

Leaching properties

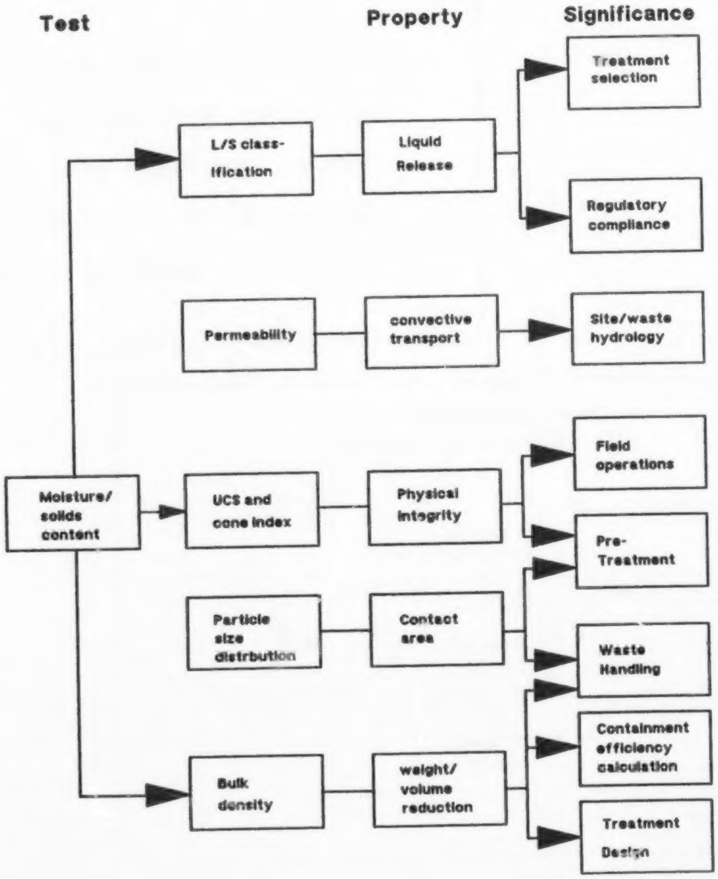
Site engineering

Climate

TESTING METHODS OF UNTREATED WASTES

- Liquid/solid classification
- Particle size and distribution
- Moisture content
- Bulk density
- Permeability
- Strength

INTERRELATION OF SITE/UNTREATED WASTE TESTING


Test
Property
Significance
Treatment selection
L/S classification
Liquid Release
Regulatory compliance
Permeability
convective transport
Site/waste hydrology
Field operations
Moisture/solids content
UCS and cone index
Physical integrity
Pre-Treatment
Particle size distrbution
Contact area
Waste Handling
Containment efficiency calculation
Bulk density
weight/volume reduction
Treatment Design

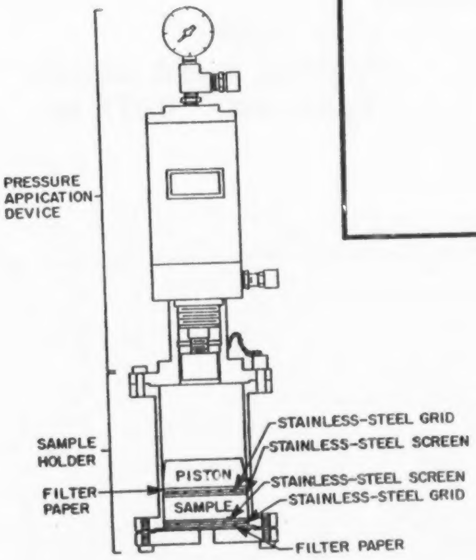
LIQUID/SOLID CLASSIFICATION

Regulation: Land ban, HSWA prohibits disposal of bulk liquid hazardous waste and hazardous waste containing free liquid

Tests:
- Paint Filter Test (SW 846-9095)
- Liquid Release Test

MEANS OF LIQUID RELEASE

- Gravitation
- Capillary forces
- Pressure
- Microstructural dehydration
- Wash out
- Degradation
  - physical
  - biological


PRESSURE APPICATION DEVICE
SAMPLE HOLDER
FILTER PAPER
PISTON
SAMPLE
STAINLESS-STEEL GRID
STAINLESS-STEEL SCREEN
STAINLESS-STEEL SCREEN
STAINLESS-STEEL GRID
FILTER PAPER

Liquid Release Test Device

PARTICLE SIZE ANALYSIS

- Objectives
    - range measurement
    - distribution measurement
- Significance
    - treatability
    - mixing

PARTICLE SIZE ANALYSIS

Continued

- Method
    - sieve analysis
      measures weight retained,
      range: mm - 0.075 mm

MOISTURE CONTENT

- Objectives
    - determine the amount of free fluid
    - determine solids content
- Significance
    - process selection/compliance
    - need of pretreatment
    - mixing ratio selection
    - field operations
- Method
    - ASTM D2216-80
    - drying at 110 C

BULK DENSITY

- Objective
  - determine weight to volume ratio
- Significance
  - weight to volume conversion (excavation, treatment, shipping) and porosity calculations
- Methods
  - drive cylinder (ASTM D2937-83)
  - sand cone (ASTM D1556-82)
  - nuclear (ASTM D2922-81)
  - screening (ASTM D3402.025)

STRENGTH TESTING

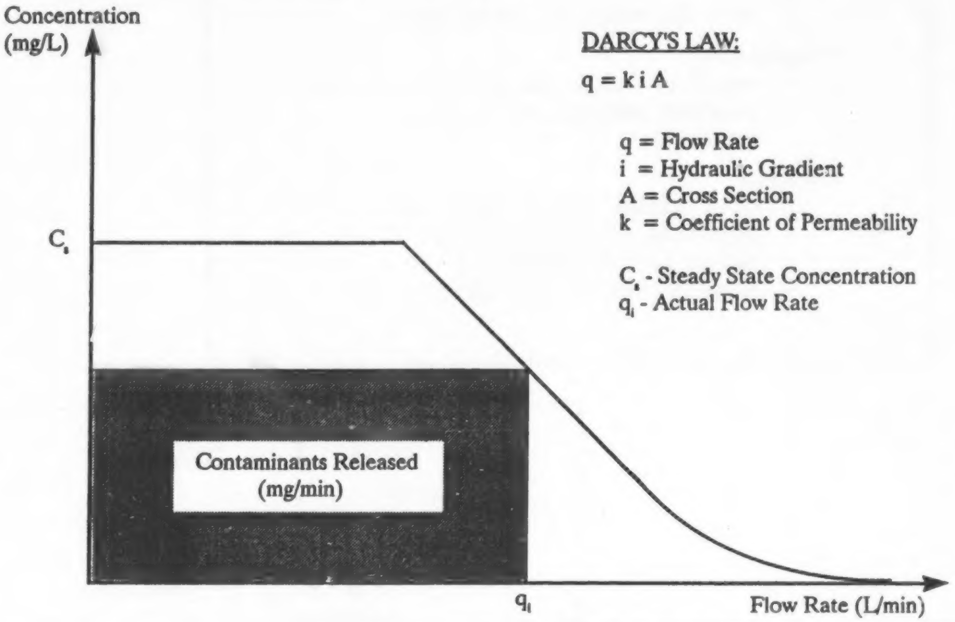
- Objective
  - determine waste/soil stability
- Significance
  - "trafficability" to construction equipment
  - "workability" - ease of processing
  - S/S baseline
- Methods
  - Unconfined Compressive Strength (UCS) (ASTM D2166-85)
  - cone index (ASTM 3441-79)

PERMEABILITY

(Hydraulic Conductivity)

- Objectives
  - measure advective transport of water through the waste
- Significance
  - affects migration of contaminants
  - directly - flow rates
  - indirectly - mechanisms of release
- Methods
  - ASTM 18.04 and D2434
  - Army Corps of Engineers EM 1110-2-1906

PERMEABILITY AND RELEASE



DARCY'S LAW:

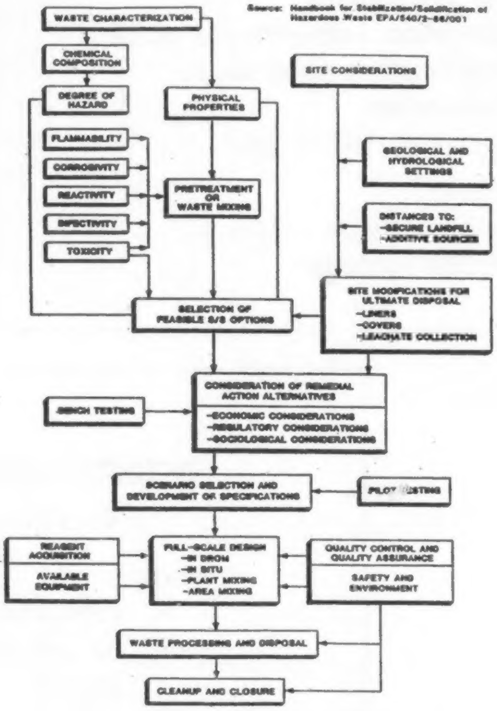
$q = k\,i\,A$

q = Flow Rate
i = Hydraulic Gradient
A = Cross Section
k = Coefficient of Permeability

C_s - Steady State Concentration
q_i - Actual Flow Rate

PERMEABILITY FIELD TESTS

- **Falling head**
- **Rising head**
- **Constant head**
- **Single well response**


WASTE CHARACTERIZATION
CHEMICAL COMPOSITION
DEGREE OF HAZARD
FLAMMABILITY
CORROSIVITY
REACTIVITY
INFECTIVITY
TOXICITY
PHYSICAL PROPERTIES
PRETREATMENT OR WASTE MIXING
SITE CONSIDERATIONS
GEOLOGICAL AND HYDROLOGICAL SETTINGS
DISTANCES TO:
-SECURE LANDFILL
-ADDITIVE SOURCES
SELECTION OF FEASIBLE S/S OPTIONS
SITE MODIFICATIONS FOR ULTIMATE DISPOSAL
-LINERS
-COVERS
-LEACHATE COLLECTION
BENCH TESTING
CONSIDERATION OF REMEDIAL ACTION ALTERNATIVES
-ECONOMIC CONSIDERATIONS
-REGULATORY CONSIDERATIONS
-SOCIOLOGICAL CONSIDERATIONS
SCENARIO SELECTION AND DEVELOPMENT OF SPECIFICATIONS
PILOT TESTING
REAGENT ACQUISITION
AVAILABLE EQUIPMENT
FULL-SCALE DESIGN
-IN DRUM
-IN SITU
-PLANT MIXING
-AREA MIXING
QUALITY CONTROL AND QUALITY ASSURANCE
SAFETY AND ENVIRONMENT
WASTE PROCESSING AND DISPOSAL
CLEANUP AND CLOSURE

Source: Handbook for Stabilization/Solidification of Hazardous Waste EPA/540/2-86/001

EVALUATING THE S/S PROCESS SELECTION

TREATABILITY STUDY STEPS

- Mixing (ASTM C-305-82)
- Compaction
  - tamping
  - shaker table
- Molding
  - cylinders
  - cubes
- Curing
  - pozzolans
  - cement

Parameters: temperature, humidity, time

INTERFERENCES

- Interfering mechanism:
  - adsorption (dicarboxylic acid)
  - complexation (sucrose)
  - precipitation
  - nucleation (silica gel)
- Accelerators:
  - triethanolamine < 0.06 %
  - calcium formate

INTERFERENCES

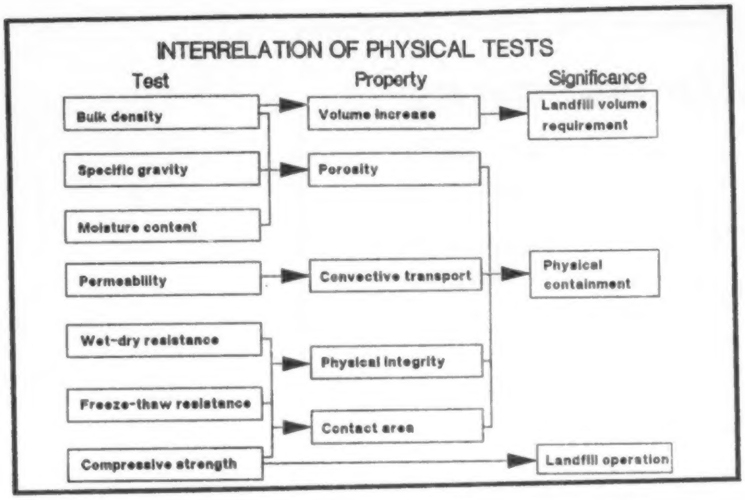
Continued

- Retarders:
  - formaldehyde
  - oil and grease
  - phenol
  - sulfates
  - metals (Pb, Cu, Zn)

PROCESS TESTING

- Mixing properties
  - heat of reaction
  - alkalinity
  - spiking
- Strength development
- Additive volume/weight control

INTERRELATION OF PHYSICAL TESTS


Test
Property
Significance
Bulk density
Specific gravity
Moisture content
Permeability
Wet-dry resistance
Freeze-thaw resistance
Compressive strength
Volume increase
Porosity
Convective transport
Physical integrity
Contact area
Landfill volume requirement
Physical containment
Landfill operation

METHOD MODIFICATIONS FOR TREATED WASTES

- UCS - cylindrical vs cube samples (D4633-84 vs C109-86) method of pre-soaking
- Permeability - flexible wall permeameter

ADDITIONAL TESTS FOR TREATED WASTES

- True density/specific gravity
- Solubility
- Weathering properties
    - wet dry (ASTM D-4843)
    - freeze thaw (ASTM D-4842)
- Biodegradation
    - fungus (ASTM G21-70)
    - bacteria (ASTM G22-76)
- Micromorphology (LSU-WES-AEC)

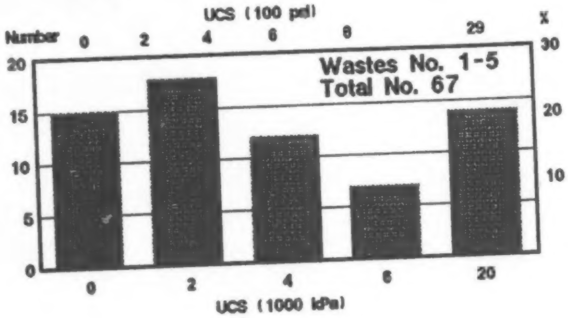
CALCULATED PROPERTIES

$$\text{Weight change factor} = \frac{\text{weight of treated waste}}{\text{weight of untreated waste}}$$

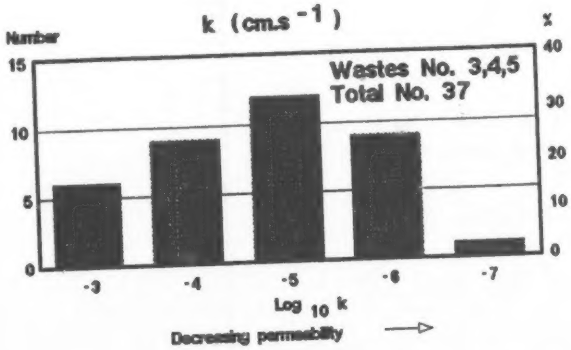
$$\text{Volume change factor} = \frac{\text{bulk density of untreated waste}}{\text{bulk density of treated waste}} \times \text{weight change factor}$$

$$\text{Porosity} = 1 - \frac{\text{bulk density of treated waste}}{\text{true density of treated waste}} (1 - \text{moisture content})$$

COMPRESSIVE STRENGTH (UCS)



PERMEABILITY

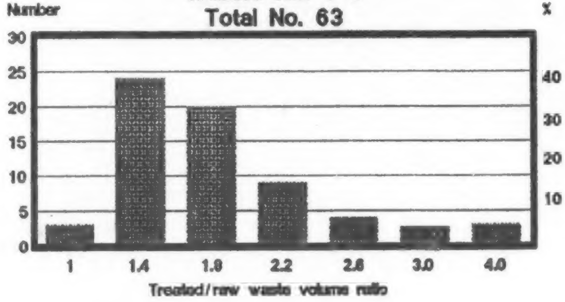


- Properties are waste dependent
- High UCS ⟶
  - good weathering durability
- Low UCS ⟶
  - not conclusive
- Freeze - Thaw Test
  - more severe than Wet - Dry Test

VOLUME INCREASE

Wastes No. 1-5

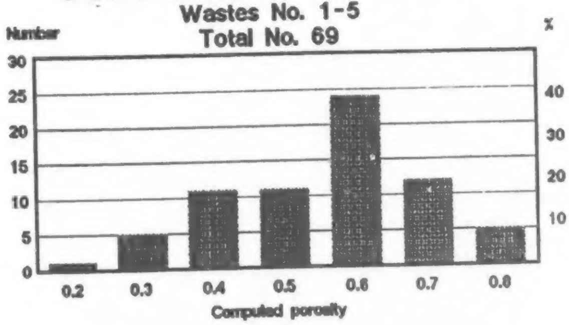
Total No. 63



COMPUTED POROSITY

Wastes No. 1-5

Total No. 69



CHEMICAL TESTING METHODS FOR DETERMINING EFFECTIVENESS OF S/S PROCESSES

SECTION 5

Abstract 5–2
Slides 5–6

CHEMICAL TESTING METHODS FOR DETERMINING EFFECTIVENESS OF S/S PROCESSES

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USEPA/RREL
Cincinnati, Ohio

Mr. Edwin Barth
USEPA/RREL
Cincinnati, Ohio

Dr. John Nobis
PEI Associates, Inc.
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Chemical testing procedures applicable to raw or untreated hazardous wastes may also have application to solidified/stabilized (S/S) wastes. This presentation is devoted largely to a discussion of leaching tests since these tests are most often used to evaluate the performance of S/S wastes as a treatment process for hazardous wastes. Emphasis is on the appropriate selection of the leaching tests and the interpretation of laboratory data. The experimental conditions affecting reproducibility of laboratory data and the limitations in extrapolating results to the field are discussed. At best, laboratory leaching data can simulate the behavior of waste forms under "ideal," static, or "worst-case" field conditions. Currently, leach tests are used to compare the effectiveness of various S/S processes, but are not verified to determine long-term leachability of a waste.

The chemistry of the waste and the leaching solution defines the types and kinetics of the chemical reactions that mobilize or demobilize contaminants in the S/S waste. Reactions that can mobilize contaminants adsorbed or precipitated within the waste form include dissolution and desorption. Under nonequilibrium conditions, these reactions compete with demobilizing reactions such as precipitation and adsorption. Nonequilibrium conditions generally develop when a S/S waste is contacted by a leaching solution and can result in a net transfer, or leaching, of contaminants into the leaching solution.

Extraction (or batch extraction) tests refer to a leaching test that generally involves agitation of ground or pulverized waste forms in a leaching solution. The leaching solution may be acidic or neutral. Also, it may vary throughout the extraction tests. Extraction tests may involve one-time or multiple extractions. In either case, leaching is assumed to reach equilibrium by the end of one extraction period; therefore, extraction tests are generally used to determine the maximum, or saturated, leachate concentrations under a given set of test conditions.

Other types of leach tests involve no agitation. The leaching of monolithic (instead of crushed) waste forms is evaluated in these tests. Leaching may occur under static or dynamic conditions, depending on the frequency of the leaching solution renewal. In static leach tests, the leaching solution is not replaced by a fresh solution; therefore, leaching takes place under static hydraulic conditions (low leaching velocities and maximum leachate concentrations for monlithic waste forms). In dynamic leach tests, the leaching solution is periodically replaced with new solution; therefore, this test simulates the leaching of a monolithic waste form under nonequilibrium conditions in which maximum saturation limits are not obtained and leaching rates are high. "Static" and "dynamic," therefore, refer to the velocity, not the chemistry of the leaching solution.

Another key difference between these two leaching tests is that extraction tests are short-term tests lasting from hours to days, whereas leach tests generally take from weeks to months. Because of the crushed nature of the waste and the larger amount of surface area available for leaching, extraction tests (although short-term) are used to simulate "worst-case" leaching conditions.

The following tests are discussed:

- Toxicity Characteristic Leaching Procedure (TCLP)
- Extraction Procedure Toxicity Test (EP Tox)
- California Waste Extraction Test (Cal WET)
- Multiple Extraction Procedure (MEP)
- Monofilled Waste Extraction Procedure (MWEP)
- Equilibrium Leach Test (ELT)
- Acid Neutralization Capacity (ANC)
- Sequential Extraction Test (SET)
- Sequential Chemical Extraction (SCE)
- Materials Characterization Center Static Leach Test (MCC-1P)
- American Nuclear Society Leach Test (ANS-16.1)
- Dynamic Leach Test (DLT)

There are various experimental factors that effect laboratory results and their interpretations. These included:

- Sample nonhomogeneity
- Curing time
- Chemical type of leachant/exractant
- Liquid to solid ratio
- Extraction time
- Particle size
- Amount of oil and grease

The impact of these and other experimental parameters must be considered in an evaluation of the results of several leaching tests on S/S wastes.

As mentioned previously, leaching tests produce results that are not directly applicable to leaching behavior in the field. Nevertheless, the results of several leaching tests or of leaching tests combined with physical tests or microscopic techniques can be used as indicators of field performance and environmental impact.

When used for comparative purposes, results from several leaching tests can help to identify field conditions that result in high concentrations of waste constituents. Therefore, these data may be used to site or design waste facilities that will minimize the leaching of hazardous constituents from the wastes. The data also may be used to predict the leaching of S/S wastes at different stages in time. For example, leaching conditions of a well-managed operational facility where the monolithic S/S waste receives maximum precipitation infiltration may be simulated by the use of the DLT, as this test involves constant renewal of the leaching solution and a monolithic waste form. For a closed facility that has a cover which is maintained and minimizes precipitation infiltration, leaching conditions may be similar to those of the MCC-1P test (i.e., static hydraulic conditions). In the long run, the liners, cover, and waste form may degrade, and leaching conditions may be similar to those found in multiple extraction tests (such as MEP and MWEP).

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OVERVIEW OF CHEMICAL TESTING SECTION

- Theory of contaminant migration
- Review of chemical testing procedures
- Review leach data

LEACH TESTING

VS

EXTRACTION TESTING

LEACH TEST PURPOSE

- Predict field performance
- Accelerated leaching
  - steady state vs rate
- Comparison

LEACH TEST VARIABLES

- Monolith vs particles
- Surface area
- Liquid/solid ratio
- Agitation vs static
- Flow rate
- Leachate composition
- Temperature

LEACH TEST SCALE

- Beaker
- Column
- Lysimeter
- Groundwater collection system

LEACH TEST DEFINITIONS

- Diffusion
- Advection
- Flux
- Porosity
- Tortuosity

COMPARE LEACH RESULTS TO

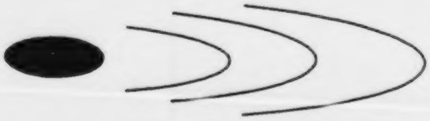
- Health based levels
- Technology based levels
- Dilution levels
- Regulatory levels
- % reduction
- Different processes

LEACHING DATA

Leach Rate $L = \frac{\text{mass}}{(\text{area})(\text{time})}$

MODELLING S/S PERFORMANCE

Use data from multiple extract leach test to estimate plume generation over time



STEP 1	Obtain leach data (ANSI 16.1)
STEP 2	Fick's law model
STEP 3	Plot cumulative released vs. time Determine release rate
STEP 4	Incorporate release rate into saturated zone model (Wilson & Miller) -velocity -aquifer thickness -waste volume -porosity

EXTRACTION TESTS

- Refers to leaching tests involving agitation of ground waste with extractant leaching solution
- May involve one-time or multiple extractions
- Used to determine the maximum or saturated leachate concentrations under a given set of test conditions

EXTRACTION TESTS

Continued

- Applicable to untreated hazardous wastes
- May also be applicable to organic solidified/stabilized wastes

	REGULATORY	TECHNICAL	RESEARCH	COMPARISON
TCLP	✓			
ANSI		✓		
MEP	✓			
ANC		✓		✓
OTHER			✓	✓

LEACH TEST METHODS AND APPLICATIONS

- TCLP (Toxic Characteristic Leaching Procedure)
- EP TOX (Extraction Procedure Toxicity Test)
- Cal WET (California Waste Extraction Test)
- MEP (Multiple Extraction Procedure)
- MWEP (Monofilled Waste Extraction Procedure)

LEACH TEST METHODS AND APPLICATIONS
Continued

- ELT (Equilibrium Leach Test)
- ANC (Acid Neutralization Capacity)
- SET (Sequential Extraction Test)
- SCE (Sequential Chemical Extraction)

LEACH/EXTRACTION TESTING

TCLP	Grind to 9.5 mm sieve(.375 in) Acetic acid(pH=3. 5)
TWA	Hexane or MeCl digestion
ANSI 16.1	Distilled water renewal No buffer

TOXIC CHARACTERISTIC LEACHING PROCEDURE (TCLP)

- Purpose - to determine amounts of constituents available for leaching in an acid medium (codisposal with municipal waste)

TCLP CAGE MODIFICATION

- Short-term tests to evaluate stability or instability of S/S wastes
- Requires tumbling a solid sample inside of stainless steel cage that is inside of TCLP extraction jar containing leaching buffer
- Well solidified wastes remain intact and poorly solidified wastes are significantly degraded

SUMMARY PROCEDURAL DIFFERENCES BETWEEN TCLP AND EP TOX

Experimental Parameter	TCLP	EP TOX
Filter size, 1×10^{-6}m	0.6-0.8	0.45
Filter pressure, psi	50	75
Leaching solution	Acetate buffered, pH approx. 3 or 5	Acetic acid, pH approx. 5
Period of extraction, H	18	24
Liquid/solid ratio	20:1	16:1

MULTIPLE EXTRACTION PROCEDURE
(MEP)

- Used for delisting
- Multiple extractions - usually nine, but more possible if last three do not decrease leachate concentrations
- Results used to determine maximum leachate concentrations
- Results used with EP Tox to compare leachability of hazardous constituents under mild and acidic conditions

CALIFORNIA WASTE EXTRACTION TEST
(Cal WET)

- Differs from the TCLP and EP TOX in the following parameters:
    - different leaching solution (sodium citrate buffered solution at pH of 5; or, for hexavalent chromium, distilled water)
    - smaller liquid to solid ratio (10:1)
    - smaller particle size (< 2.0 mm)
    - longer extraction period (48 hrs.)

ANSI 16.1

- Infinite leachant
  (5 day, 90 day)
- QC
- Indicator of performance with model
- Utilized by NRC

ANS-16.1 PROCEDURE

- Monolithic cylinder (length:diameter 0.2-5.0)
- Leached with distilled water at V/S ratio of 10 cm at ambient temperature
- Rinse sample to zero contamination at surface
- Immerse in water which is replaced after 2, 7, 24, 48, 72 hrs., and then 4, 5, 14, 28, 43, 90 days

PSA MODIFIED ANSI/ANS-16.1 LEACH METHOD

- Developed to deal with specific sample preparation & handling required by soft & porous waste forms from hydraulic binders, e.g. cements, pozzolans, gypsums, phosphates, etc.
- Changes made in (1) specimen preparation & handling, (2) site-specific leachant, (3) vessel material & cleaning procedure, (4) leachate handling & stabilization, (5) variable length leach intervals, & (6) statistical design

DYNAMIC LEACH TEST (DLT)

- Modified version of ANS-16.1 which renews leaching solutions more frequently and changes V/S ratio
- Results on cement containing heavy metals show that Leachate Index (LX) values vary within 1 unit
- Organic compounds have LX values between 5-10 (higher leach rates) and metals higher (slower rates)

MATERIALS CHARACTERIZATION CENTER STATIC LEACHING TEST (MCC-1P)

- Static leaching test developed for high-level radioactive waste
- Involves leaching monolith with water at ratio of leaching solution to surface area solids (V/S) of 10 - 200 cm
- Period and temperature of extraction may vary
- Used for organic and polymer S/S processes

MONOFILL WASTE EXTRACTION PROCEDURE (MWEP)

- Formerly Solid Waste Leach Test (SWLT)
- Involves multiple extractions of a monolith or crushed waste with water
- Used to derive reasonable leachate compositions in monofilled disposal facilities

ACID NEUTRALIZATION CAPACITY
(ANC)
Continued

- Test used to determine buffering capacity of solidified/stabilized waste form
- The higher the buffering capacity of the waste, the greater the possibility of maintaining alkaline conditions and minimizing the amount of metals leached

NOTE:

PC - Portland Cement
KD - Kiln Dust
LF - Lime/Flyash

PHASE I SARA BDAT PROGRAM
Synthetic Soil III

Metal	Raw TWA	Raw TCLP	Treated TCLP	% Removal	Binder
As	690	6.39	ND	100	PC
Cd	2380	33.1	ND	100	PC,KD
Cr	1260	ND	.07	increase	PC,KD,LF
Cu	9550	60.7	.09	100	PC
Pb	15100	19.9	ND	100	PC
Ni	1540	17.5	ND	100	PC
Zn	34450	359	0.69	100	PC

PHASE I SARA BDAT PROGRAM
Synthetic Soil IV

Metal	Raw TWA	Raw TCLP	Treated TCLP	% Removal	Binder
As	540	9.58	ND	100	PC
Cd	3790	35.3	ND	100	PC,KD,LF
Cr	1400	.06	.07	increase	PC,KD,LF
Cu	11250	10.0	0.17	100	PC
Pb	15660	70.4	0.37	99	PC
Ni	1550	26.8	ND	100	PC,KD,LF
Zn	26660	396	0.74	100	PC

OKLAHOMA SITE

TCLP Results

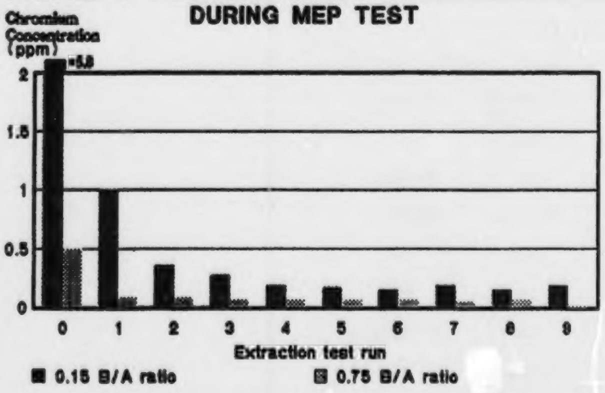
Volatiles	Untreated	Treated
Benzene	ND-TR	ND
Ethyl Benzene	ND-TR	ND
Toluene	TR-0.027	ND

FLORIDA SITE

Treated Waste ppm

	MCC	ANS 16.1	EP Tox	OILY EP
Lead	0.05	0.03	0.4	61
PCBs	0.001	0.001	N/A	N/A

FIGURE 1. CHROMIUM LEACH CONCENTRATIONS DURING MEP TEST



ORGANOPHILIC CLAY RESULTS

	Raw TWA	Treated TWA	Treated TCLP
Bis (2-chloro isopropyl ether)	8528	ND	ND
Naphthalene	18060	1445	ND
Phenanthrene	20184	ND	ND
Benzo (A) anthracene	30460	ND	ND

CONCLUSIONS

- Leaching tests not directly applicable to leaching in the field
- Results of several leaching tests and some physical tests can be used as indicators of field performance
- Data may be used to design waste facilities that will minimize the leaching of hazardous constituents
- Data may also assist in predicting the leaching of S/S wastes at different stages in time

TECHNOLOGY SCREENING PROCEDURES FOR DETERMINING IF S/S SHOULD BE IMPLEMENTED

SECTION 6

Abstract	6–2
Slides	6–4

TECHNOLOGY SCREENING PROCEDURES FOR DETERMINING IF S/S SHOULD BE IMPLEMENTED

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The decision on whether to use S/S, another technology or a combination of technologies at a site requires the evaluation of fundamental concepts, experience and the results of laboratory and pilot-scale tests. This section presents a series of steps to be taken in the selection process. It discusses the following factors and their interrelations:

1. Waste Characteristics
2. Technology/Binder Selection
3. Pretreatment Requirements
4. Site Characteristics
5. "Product" Acceptability Tests
6. The Iterative Nature of the Screening Process

This discussion builds on the concepts described in the earlier section, "Description of S/S Technologies." It combines the concepts with empirical results obtained in the past and gives guidelines for how one should set up a screening program appropriate to a specific waste/site problem.

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Weitzman, L., Hamel, L.R., Cadmus, S.R. Volatile Emissions from Hazardous Waste Final Report Prepared for the U.S. Environmental Protection Agency, Risk Reduction Engineering Laboratory, Contract 68-02-3993, WA 32, 34.

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Wiles, C.C. A Review of Solidification/Stabilization Technology, Journal of Hazardous Materials, 14(1987)5-21, Also available as EPA/600/J-87/019

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GOALS OF TECHNOLOGY SCREENING

1. To determine suitability and likelihood of success of immobilization
2. To select appropriate immobilization technologies
    - a. for RCRA TSD facilities
    - b. for CERCLA remediations (and RCRA corrective actions)

WHAT DOES GOAL NO. 1 REALLY MEAN?

In the broadest sense EVERY WASTE is potentially suitable for immobilization

---

BOTH SUITABILITY AND LIKELIHOOD OF SUCCESS DEPEND UPON

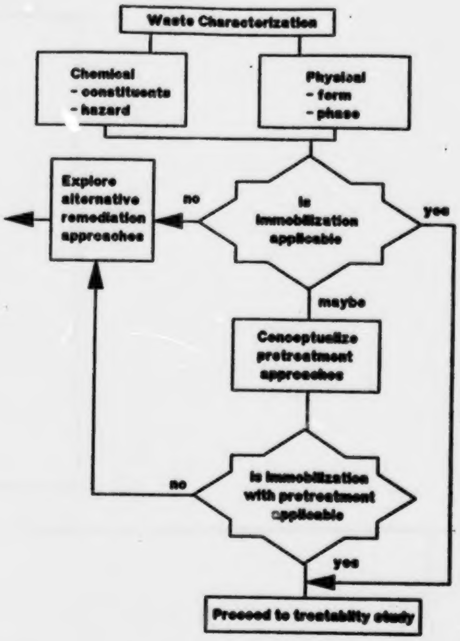
- Matching the waste to appropriate immobilization technologies
- Matching each technology's needs (along with the waste's characterization) to appropriate pretreatment requirements

SCREENING

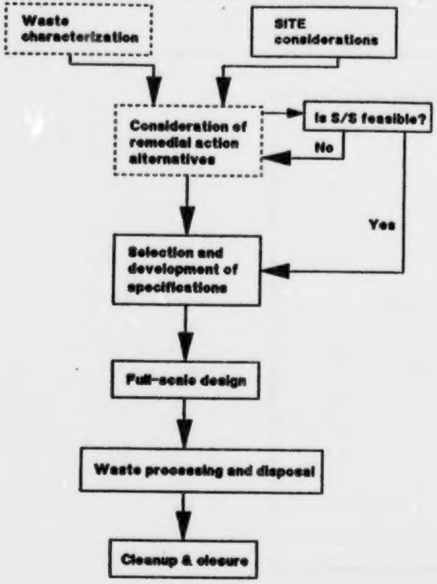
Comparing waste characteristics to technology capabilities is NOT a "one-time" operation

It is reiterated (at greater depth) throughout the technology selection process at such stages as

- **"conceptual" screening**
- **detailed screening**
- **feasibility study**
- **process design**


Waste Characterization
Chemical
- constituents
- hazard
Physical
- form
- phase
Explore alternative remediation approaches
no
Is immobilization applicable
yes
maybe
Conceptualize pretreatment approaches
no
Is immobilization with pretreatment applicable
yes
Proceed to treatability study

EVALUATION AND SELECTION OF IMMOBILIZATION FOR SITE REMEDIATION (CERCLA or RCRA C.A.)


Waste characterization
SITE considerations
Consideration of remedial action alternatives
Is S/S feasible?
No
Yes
Selection and development of specifications
Full-scale design
Waste processing and disposal
Cleanup & closure

IMPORTANT WASTE CHARACTERISTICS
Chemical Composition
(Concentration & toxicity of each constituent)

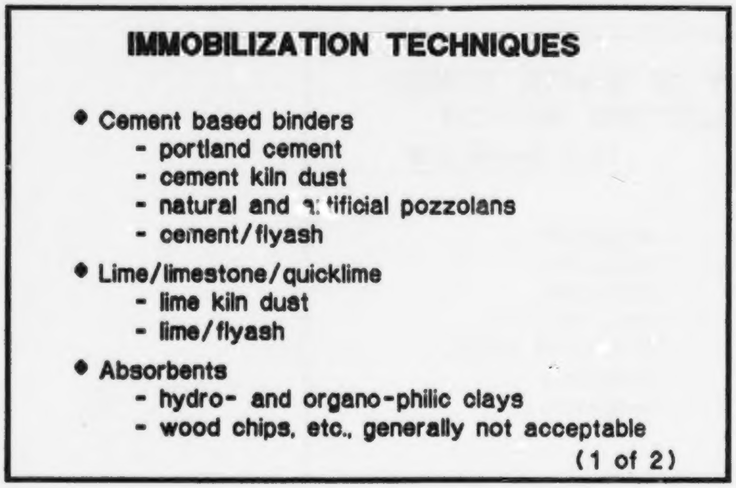
- Organic components
  - polar, nonpolar
  - volatile, semivolatile, nonvolatile
- Inorganics
  - acids
  - oxidizers
  - metals
  - soluble salts

IMPORTANT WASTE CHARACTERISTICS
Physical Characteristics

- Phase & form (liquid, solid, sludge, soils)
- Total solids
- Particle size distribution
- Presence of debris

How do we match waste characteristics

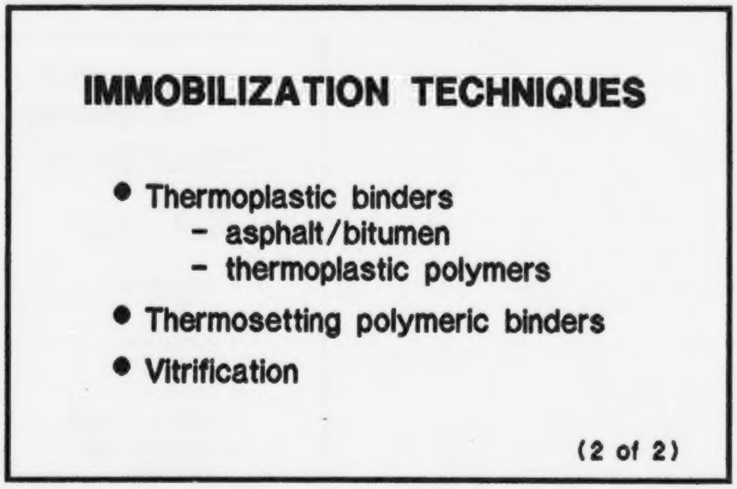
to potential immobilization technologies?



IMMOBILIZATION TECHNIQUES

- Cement based binders
  - portland cement
  - cement kiln dust
  - natural and artificial pozzolans
  - cement/flyash
- Lime/limestone/quicklime
  - lime kiln dust
  - lime/flyash
- Absorbents
  - hydro- and organo-philic clays
  - wood chips, etc., generally not acceptable

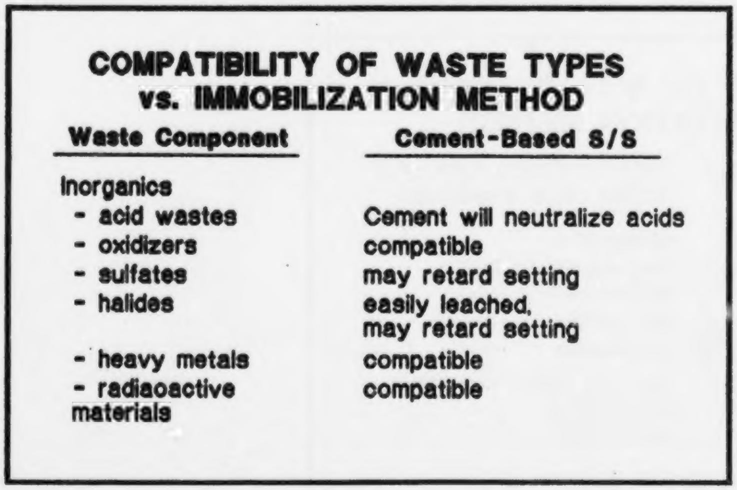
(1 of 2)



IMMOBILIZATION TECHNIQUES

- Thermoplastic binders
  - asphalt/bitumen
  - thermoplastic polymers
- Thermosetting polymeric binders
- Vitrification

(2 of 2)



COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Cement-Based S/S
Inorganics	
- acid wastes	Cement will neutralize acids
- oxidizers	compatible
- sulfates	may retard setting
- halides	easily leached, may retard setting
- heavy metals	compatible
- radioactive materials	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Lime-Based S/S
Inorganics	
- acid wastes	compatible
- oxidizers	compatible
- sulfates	compatible
- halides	easily leached, may retard setting
- heavy metals	compatible
- radiaoactive materials	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Thermoplastic solidification (little data available)
Inorganics	
- acid wastes	should be neutralized before incorporation
- oxidizers	may cause matrix breakdown; fire
- sulfates	may dehydrate and rehydrate causing splitting
- halides	may dehydrate
- heavy metals	compatible
- radiaoactive materials	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Thermosetting Polymers (little data available)
Inorganics	
- acid wastes	compatible
- oxidizers	may cause matrix breakdown
- sulfates	compatible
- halides	compatible
- heavy metals	acid pH solubilizes metal hydroxides
- radiaoactive materials	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Vitrification
Inorganics	
- acid wastes	should first be neutralized
- oxidizers	will react in process
- sulfates	compatible
- halides	fluorine-silicate interactions possible (defluorination as pretreatment)
- heavy metals	compatible
- radioactive materials	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Cement-Based S/S
Organics*	
- nonpolar	impedes setting, volatiles will escape in processing
- polar	may significantly retard setting, decreases durability

* Generally, organics should be removed or destroyed as "pretreatment" before cement-based S/S

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Lime-Based S/S
Organics*	
- nonpolar	impedes setting, decreases durability, volatiles may escape
- polar	phenols and alcohols retard setting, decreases durability

* Generally, organics should be removed or destroyed as "pretreatment" before lime-based S/S

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Thermoplastic Solidification
Organics	
- nonpolar	compatible, may vaporize upon heating
- polar	compatible, may vaporize upon heating

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Thermosetting polymers
Organics	
- nonpolar	may impede setting
- polar	compatible

COMPATIBILITY OF WASTE TYPES vs. IMMOBILIZATION METHOD

Waste Component	Vitrification
Organics*	
- nonpolar	will volatilize, will combust if oxygen is available
- polar	will volatilize, will combust if oxygen is available

* Vitrification of residues as part of an organics incineration scheme is often proposed

COMPATIBILITY OF PHYSICAL CHARACTERISTICS vs. IMMOBILIZATION METHOD

Waste Component	Cement-Based Binders
Phase or Form	
- liquid	acceptable
- sludge	acceptable (pumping concerns)
- solid	acceptable (mixing concerns), solids must be wettable
- contaminated soil	acceptable
- total solids	any range
particle size dist.	prefer smaller size and random distribution
Presence of debris	must be removed

COMPATIBILITY OF PHYSICAL CHARACTERISTICS vs. IMMOBILIZATION METHOD

Waste Component	Lime-Based Binders
Phase or Form	
- liquid	acceptable
- sludge	acceptable (pumping concerns)
- solid	acceptable (mixing & wetting concerns)
- contaminated soil	acceptable
- total solids	any range (0-100%)
- particle size dist.	prefer smaller size and random distribution
- Presence of debris	must be removed

COMPATIBILITY OF PHYSICAL CHARACTERISTICS vs. IMMOBILIZATION METHOD

Waste Component	Thermoplastic
Phase or Form	
- liquid	aqueous liquids not applicable
- sludge	water evaporated in process
- solid	acceptable
- contaminated soil	acceptable
- total solids	10-100%
- particle size dist.	smaller size preferred
- Presence of debris	must be removed

COMPATIBILITY OF PHYSICAL CHARACTERISTICS vs. IMMOBILIZATION METHOD

Waste Component	Thermosetting polymers
Phase or Form	
- liquid	information lacking
- sludge	
- solid	
- contaminated soil	
- total solids	
- particle size dist.	
- Presence of debris	

COMPATIBILITY OF PHYSICAL CHARACTERISTICS vs. IMMOBILIZATION METHOD

Waste Component	Vitrification
Phase or Form	
- liquid	not applicable
- sludge	dewatering required
- solid	acceptable
- contaminated soil	acceptable
- total solids	40% - 100%
- particle size dist.	in reactor - solids should be crushed in situ - no restrictions
- Presence of debris	in reactor - remove debris in situ - no metallic debris › 0.9 X electrode spacing

INTERFERENCES TO CHEMICAL S/S SYSTEMS

- Sulfur
- Calcium chloride
- Sodium arsenate
- Sodium borate
- Sodium phosphate
- Sodium halides
- Soluble metal salts
    - tin, zinc, copper, lead

MANIFESTATIONS OF INTERFERING CONSTITUENTS

- Spalling and cracking
- Set retardation; hardening and waste containment are impeded
- Flash set; mixing incomplete as a result of quick set, equipment can be fouled

(1 of 2)

MANIFESTATIONS OF INTERFERING CONSTITUENTS

- Chelated/complexed toxic constituents may accelerate leaching, even if waste is successfully S/S
- Some waste constituents can react and cause swelling and disintegration of S/S mass long after setting reactions complete
- Oxidizers can cause slow deterioration of the organic binder matrix

(2 of 2)

INTERACTIONS BETWEEN S/S BINDERS AND SPECIFIC ORGANICS

	Portland Cement		
Organic Compounds	Type 1	Type II & IV	Clay-Cement
Alcohols & Glycols	Durability: decrease	Durability: decrease	Durability: decrease
Aliphatic & Aromatic Hydrocarbons	Set time: increase Durability: no effect	Set time: increase	Data unavailable
Chlorinated	Set time: increase Durability: decrease	Set time: increase Durability: decrease	Data unavailable

INTERACTIONS BETWEEN S/S BINDERS AND SPECIFIC INORGANICS

Chemical Group	Portland Cement		Clay-Cement
	Type 1	Type II & IV	
Heavy Metal Salts & Complexes	Set time: increase Durability: decrease	Set time: increase Durability: no change	Set time: increase Durability: decrease
Inorganic Acids	Set time: no effect Durability: decrease	Set no effect Durability: no effect	Durability: decrease
Inorganic Bases	Set time: no effect Durability: no effect	Set time: no effect Durability: no effect Durability (decreases with KOH & NaOH)	Durability: decrease

In general, one or more methods of immobilization will be good candidates as part of an integrated process for ANY waste.

GOALS OF TECHNOLOGY SCREENING

1. To determine suitability and likelihood of success of immobilization
2. To select appropriate immobilization technologies
   a. for RCRA TSD facilities
   b. for CERCLA remediations (and RCRA corrective actions)

DIFFERENCE BETWEEN GOALS 2a AND 2b

- RCRA treatment facilities will be driven by the regulations and by the technology they have available in their facility
- RCRA land disposal facilities will be driven by regulations
- Remediation actions will have the full set of technologies as options
- Remedial actions will be driven by site characteristics and regulatory and institutional restrictions as well as waste characteristics

GOALS OF TECHNOLOGY SCREENING

1. To determine suitability and likelihood of success of immobilization
2. To select appropriate immobilization technologies
    - a. for RCRA TSD facilities
    - b. for CERCLA remediations (and RCRA corrective actions)

Any one treatment facility will probably have one (or a few) specific immobilization technologies in place

and

will have a limited menu of pretreatment options available

- AND SO -

"Screening" at a RCRA TSD Facility means determinig whether each proposed waste is treatable by that immobilization technology

TSD

Treatment, Storage, and Disposal of hazardous wastes under the Resource Conservation and Recovery Act (RCRA) and subsequent amendments. A unit or facility which disposes of RCRA wastes at the facility may also be referred to as a "secure landfill" or "minimum technology unit"

SCREENING CONCERNS

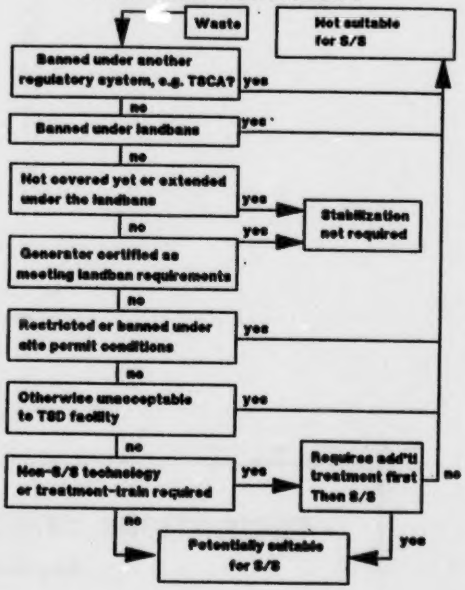
Treatment vs. Disposal Facilities

- Treatment question - can "this" waste be treated to be acceptable for disposal
- Disposal question - can "that" material pass all the required tests for acceptance here

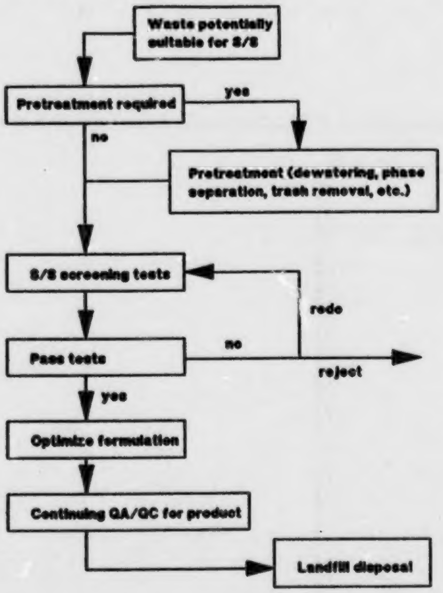
SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods

DETERMINING IF S/S IS APPLICABLE AT A RCRA TSD FACILITY


Waste
Not suitable for S/S
Banned under another regulatory system, e.g. TSCA?
yes
no
Banned under landbans
yes
no
Not covered yet or extended under the landbans
yes
Stabilization not required
no
yes
Generator certified as meeting landban requirements
no
Restricted or banned under site permit conditions
yes
no
Otherwise unacceptable to TSD facility
yes
no
Non-S/S technology or treatment-train required
yes
Requires add'tl treatment first Then S/S
no
no
yes
Potentially suitable for S/S

S/S DECISION TREE AT A RCRA TSD FACILITY


Waste potentially suitable for S/S
Pretreatment required
yes
no
Pretreatment (dewatering, phase separation, trash removal, etc.)
S/S screening tests
redo
Pass tests
no
reject
yes
Optimize formulation
Continuing QA/QC for product
Landfill disposal

SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods

REGULATIONS AFFECTING DISPOSAL

- Landbans
- Permit Conditions
- TSD Conditions
- Other Regulatory Systems

REGULATIONS AFFECTING DISPOSAL

Landbans

- Liquid-in-Landfill Ban
- Solvent Ban
- California List Ban
- Scheduled Wastes
    - First Third
    - Second Third
    - Third Third
    - Soft-Hammer
    - Extensions

REGULATORY LEVELS IN LEACHATES AFTER 2nd 3rd LANDBAN

(July 1989)

Concentration of Constituent (mg/l) in Waste or Leachate

Description	As	Ba	Cd	Cr	Pb	Hg	Ni	Se	Ag
Lowest level in any 1st3rd waste code	0.004		0.066	0.094	0.180	0.025	0.048	0.025	0.072
Delisting levels	0.315	6.300	0.063	0.315	0.315	0.013	3.150 2.205	0.063	0.315
RCRA Characteristic levels	5.000	100.0	1.000	5.000	5.000	0.200		1.000	5.000
Drinking water stds.	0.050	1.000	0.010	0.050	0.050	0.002		0.010	0.050

REGULATIONS AFFECTING DISPOSAL

Permit Conditions

- EPA Region
- State

REGULATIONS AFFECTING DISPOSAL
TSD Conditions

- Company Policy
- Protection of Landfill Liners

REGULATIONS AFFECTING DISPOSAL
Other Regulatory Systems

- TSCA: PCBs

SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods

SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

Waste Characteristics

- Chemical Characteristics
  - Metal Content
  - Metal Speciation
  - Reactivity
    - Presence of Cyanide or Sulfide

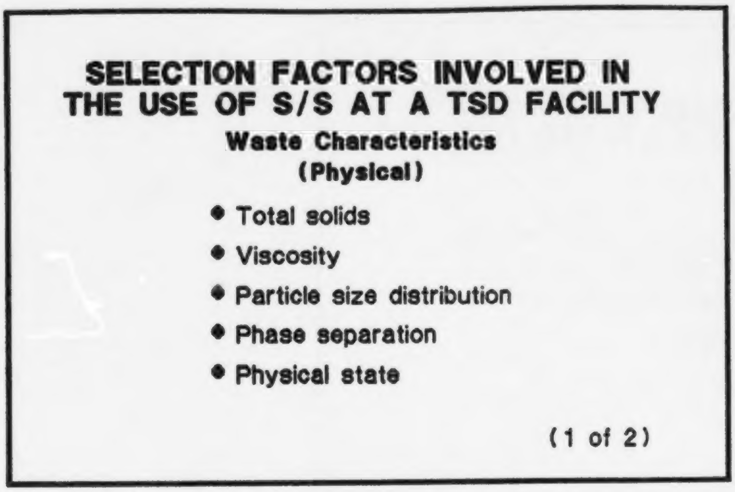
(1 of 2)

SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

Waste Characteristics

- Chemical Characteristics
  - Corrosivity
  - Ignitability
  - Organic content
    - Non-toxic Organics
    - Toxic organics
    - Volatile organics
  - Radioactivity

(2 of 2)

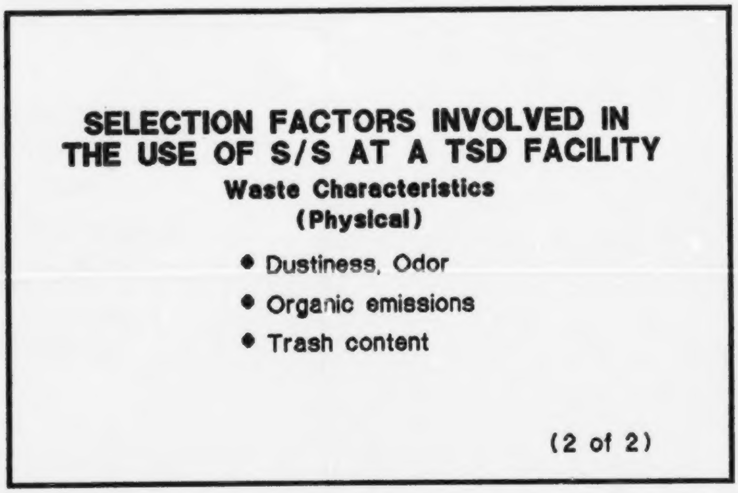


SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

Waste Characteristics
(Physical)

- Total solids
- Viscosity
- Particle size distribution
- Phase separation
- Physical state

(1 of 2)

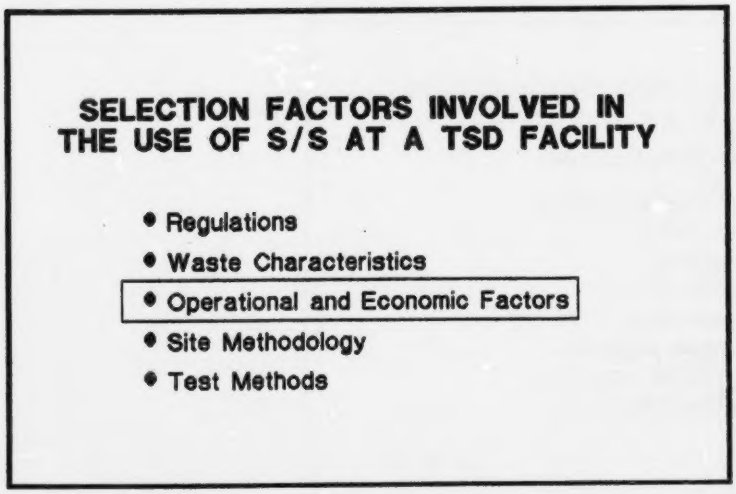


SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

Waste Characteristics
(Physical)

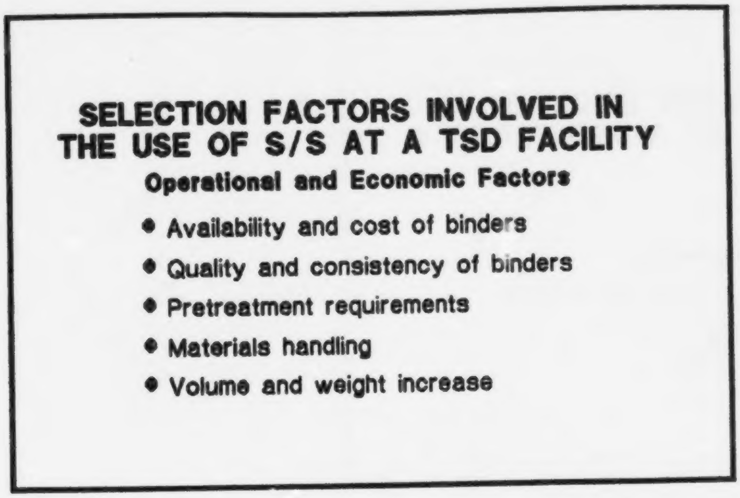
- Dustiness, Odor
- Organic emissions
- Trash content

(2 of 2)



SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

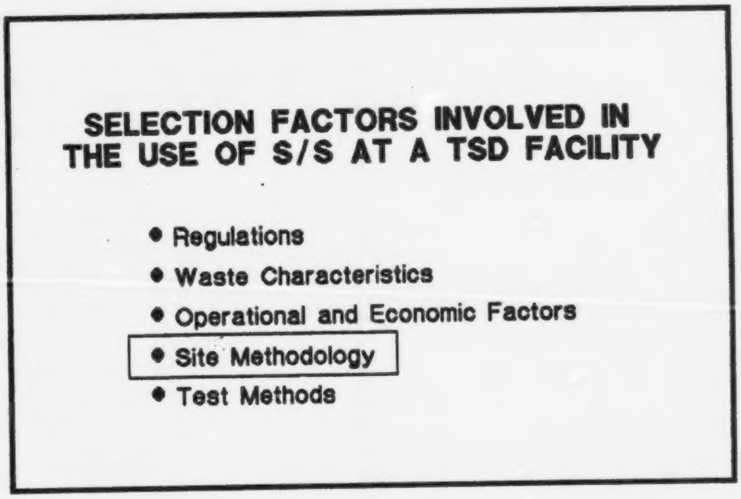
- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods



SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

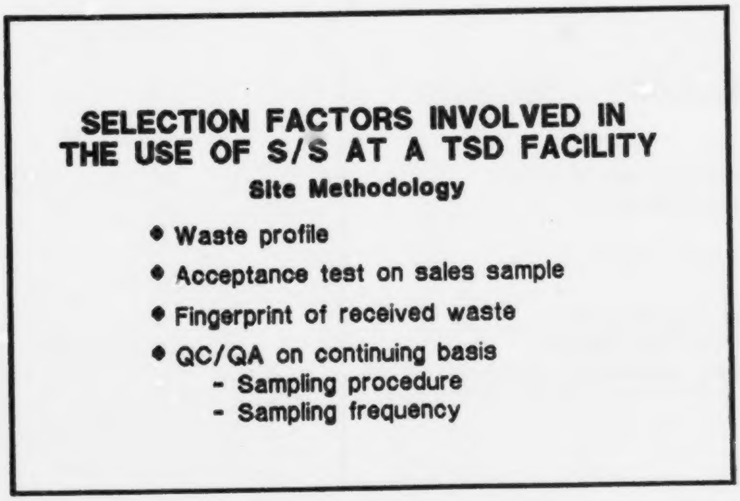
Operational and Economic Factors

- Availability and cost of binders
- Quality and consistency of binders
- Pretreatment requirements
- Materials handling
- Volume and weight increase



SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods



SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

Site Methodology

- Waste profile
- Acceptance test on sales sample
- Fingerprint of received waste
- QC/QA on continuing basis
  - Sampling procedure
  - Sampling frequency

SELECTION FACTORS INVOLVED IN THE USE OF S/S AT A TSD FACILITY

- Regulations
- Waste Characteristics
- Operational and Economic Factors
- Site Methodology
- Test Methods

DETERMINING FACTORS IN THE ACCEPTABILITY OF "IMMOBILIZED" WASTE AT A TSD FACILITY

Test Methods

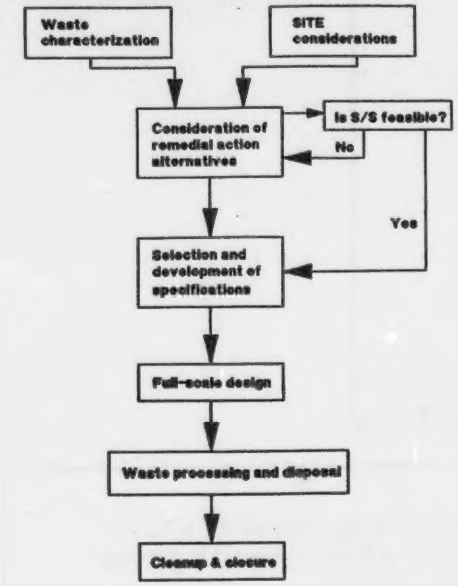
- Paint Filter Test (PFT)
- Toxicity Characteristic Leaching Procedure (TCLP)
- Site specific tests
  - Screens for:
    - Ignitability
    - Corrosivity
    - Reactivity
    - Radioactivity

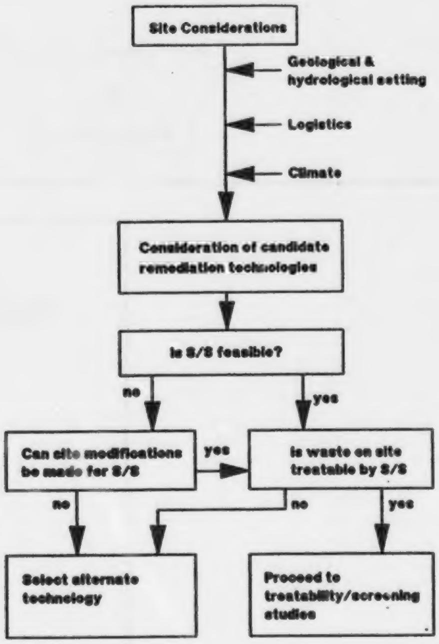
GOALS OF TECHNOLOGY SCREENING

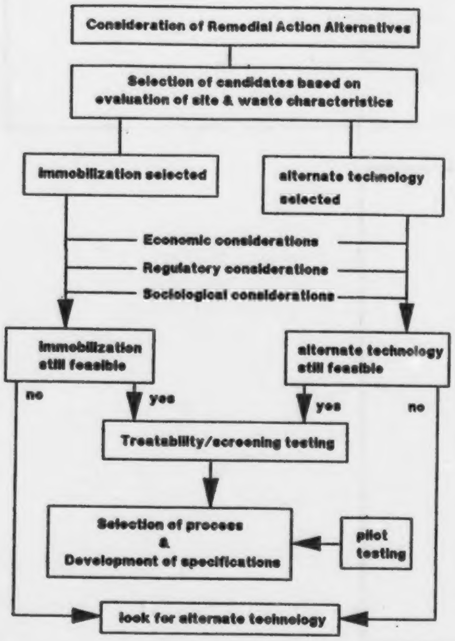
1. To determine suitability and likelihood of success of immobilization

2. To select appropriate immobilization technologies
   a. for RCRA TSD facilities
   b. for CERCLA remediations (and RCRA corrective actions)

EVALUATION AND SELECTION OF IMMOBILIZATION FOR SITE REMEDIATION (CERCLA or RCRA C.A.)

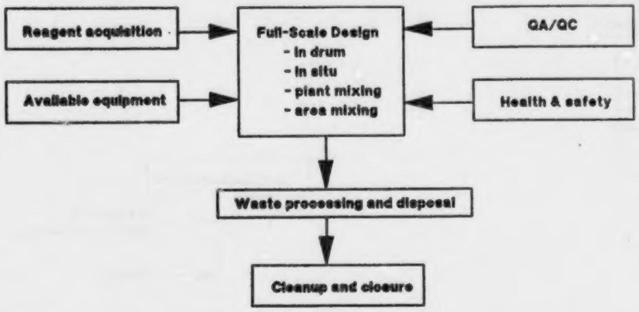

Waste characterization
SITE considerations
Consideration of remedial action alternatives
Is S/S feasible?
No
Yes
Selection and development of specifications
Full-scale design
Waste processing and disposal
Cleanup & closure


Site Considerations
Geological & hydrological setting
Logistics
Climate
Consideration of candidate remediation technologies
Is S/S feasible?
no
yes
Can site modifications be made for S/S
yes
Is waste on site treatable by S/S
no
no
yes
Select alternate technology
Proceed to treatability/screening studies


Consideration of Remedial Action Alternatives
Selection of candidates based on evaluation of site & waste characteristics
immobilization selected
alternate technology selected
Economic considerations
Regulatory considerations
Sociological considerations
immobilization still feasible
alternate technology still feasible
no
yes
yes
no
Treatability/screening testing
Selection of process & Development of specifications
pilot testing
look for alternate technology

FULL SCALE PROCESS DESIGN

CERCLA Sites


Reagent acquisition
Available equipment
Full-Scale Design
- in drum
- in situ
- plant mixing
- area mixing
QA/QC
Health & safety
Waste processing and disposal
Cleanup and closure

FACTORS IN SELECTING AN IMMOBILIZATION PROCESS/SYSTEM

- Waste characteristics
- Immobilization technology
- Site characteristics
    - water table
    - climate
    - soil characteristics
    - site layout
    - logistics
    - other

SITE CHARACTERISTICS

Will Limit:

- Immobilization technology chosen
- Pretreatments used (further limiting technologies)
- The full-scale design process
- Final specifications imposed on the immobilized product to be disposed
    - if on site, spec's determined for each site
    - if off site, spec's same as TSD

SITE CONSIDERATIONS

- Water table
- Climate
- Soil characteristics
- Site layout
- Logistics
- Other

WATER TABLE & CLIMATE

Questions to be Answered First

- Does immobilization require engineered controls to allow implementation and placement on site
- Will immobilized material be disposed off site

WATER TABLE/RAINFALL

Wetter Engineered controls needed **Drier**
←
for on-site disposal

Higher Cost of on-site disposal **Lower**
←

Note: On site means at the CERCLA remedial site
Off site means final disposal at another location

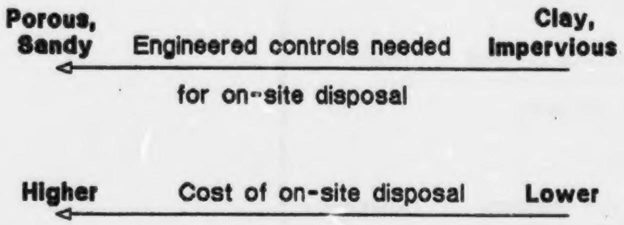
ENGINEERED CONTROLS

- Dikes
- Berms
- Groundwater diversion
- Liners; grout curtains
- Waste isolation

SITE CONSIDERATIONS

- Water table
- Climate
- Soil characteristics
- Site layout
- Logistics
- Other

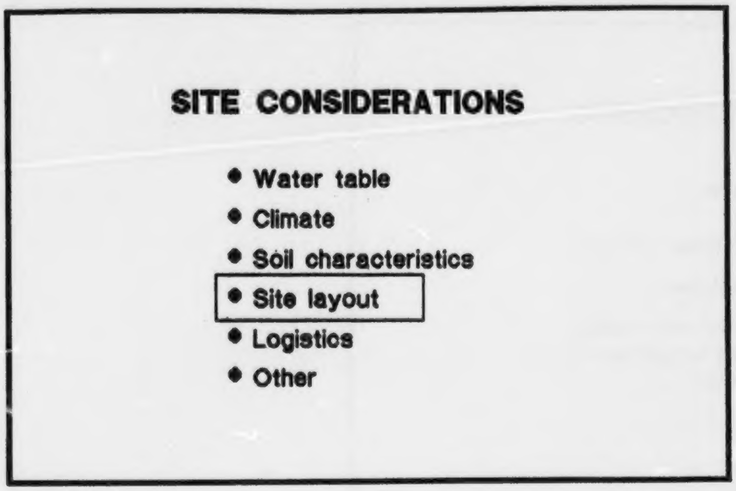
SOIL TYPE



Porous, Sandy Engineered controls needed for on-site disposal **Clay, Impervious**

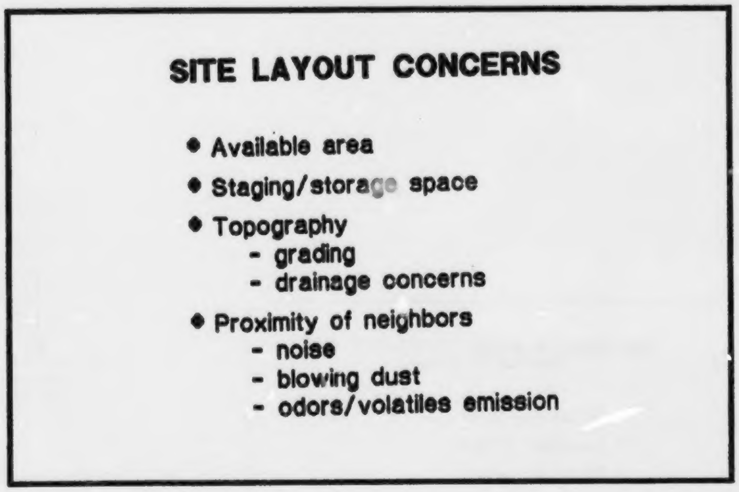
Higher Cost of on-site disposal **Lower**

Note: On site means at the CERCLA remedial site
Off site means final disposal at another location



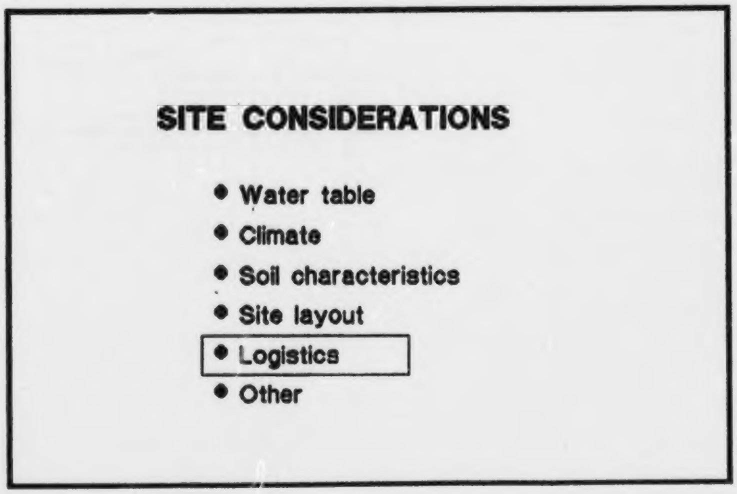
SITE CONSIDERATIONS

- Water table
- Climate
- Soil characteristics
- Site layout
- Logistics
- Other



SITE LAYOUT CONCERNS

- Available area
- Staging/storage space
- Topography
  - grading
  - drainage concerns
- Proximity of neighbors
  - noise
  - blowing dust
  - odors/volatiles emission

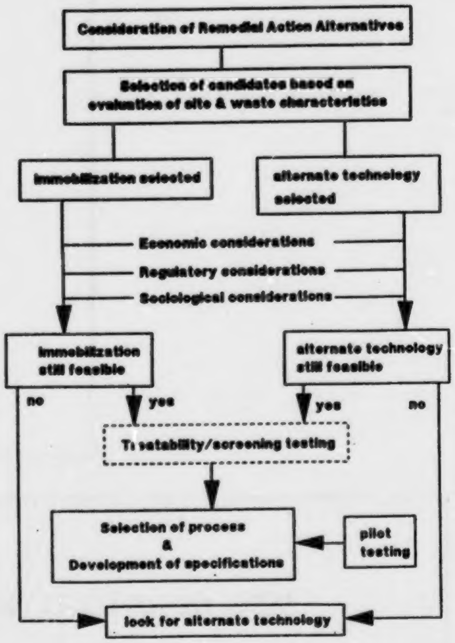


SITE CONSIDERATIONS

- Water table
- Climate
- Soil characteristics
- Site layout
- Logistics
- Other

LOGISTIC CONCERNS

- Available access
  - equipment
  - binder material delivery
- Proximity to suppliers
- Proximity to disposal facility (if immobilized product is to be disposed off site)


Consideration of Remedial Action Alternatives
Selection of candidates based on evaluation of site & waste characteristics
immobilization selected
alternate technology selected
Economic considerations
Regulatory considerations
Sociological considerations
immobilization still feasible
alternate technology still feasible
no
yes
yes
no
Treatability/screening testing
Selection of process & Development of specifications
pilot testing
look for alternate technology

TREATABILITY STUDY TO SELECT S/S BINDER SYSTEM

- Sampling program
- Analytical program
- Binder screening
- Binder quantity determination
  - S/S product performance
  - Criteria for success
- QA/QC for all steps

SAMPLING PROGRAM

- Waste characteristics
- Soil characteristics
- Site characteristics
- Specific considerations noted

ANALYTICAL PROGRAM

- What tests/measurements?
- Accuracy; reproducibility
- How many measurements necessary?
  -statistics

TREATABILITY STUDY TO SELECT S/S BINDER SYSTEM

- Sampling program
- Analytical program
- Binder screening
- Binder quantity determination
  - S/S product perfromance
  - Criteria for success
- QA/QC for all steps

SCREENING OF BINDER SYSTEM

- Which candidate systems meet physical requirements
- Which candidate systems meet chemical (leaching) requirements

PHYSICAL SCREENING

- Will the binder/waste matrix harden?
  - penetrometer
  - UCS
  - visual

CHEMICAL (LEACHING) SCREENING

- Will the binder/waste matrix pass applicable tests
  - EP toxicity
  - TCLP
  - ANS 16.1
  - WET
  - etc.

TREATABILITY STUDY TO SELECT S/S BINDER SYSTEM

- Sampling program
- Analytical program
- Binder screening
- Binder quantity determination
    - S/S product perfromance
    - Criteria for success
- QA/QC for all steps

BINDER QUANTITY DETERMINATION

- Set up screening tests at varying ratios of:
    - binder to contaminated soil or waste
    - water to binder, or water to solids
- Measure performance at each condition

EXAMPLE

- Screening tests
    - binder:waste (B/W) 0.1, 0.5, 1.0,.....
    - water:solids (W/S) 0.5, 0.7, 1.0,.....
- Will it harden in 24 hours
    - UCS
    - penetrometer
    - visual

Within general ranges of system selected

prepare a large number of samples

for further testing

CHEMICAL SCREENING TEST

Using the lowest addition that hardened to selected criteria

- TCLP
- EP toxicity
- MEP
- ANSI 16.1

WHAT RATIO WILL HARDEN IN 24 HOURS?

B/W \ W/S	0.5	0.7	1.0
0.1	2*	2*	2*
0.5	2*	2*	2*
0.7	2*	2*	2*

* - No. of samples

- Test for hardness at 24 hours
- Will give a broad range for more specific testing

NARROW RANGE FOR TESTING BASED ON SCREENING RESULTS

W/S B/W	0.5	0.6	0.7
0.2	X	X	X
0.3	X	X	X
0.4	X	X	X
0.5	X	X	X

TREATABILITY STUDY TO SELECT S/S BINDER SYSTEM

- Sampling program
- Analytical program
- Binder screening
- Binder quantity determination
  - S/S product perfromance
  - Criteria for success
- QA/QC for all steps

Regulatory guidance on product "specification" (e.g. leaching standards, performance criteria, etc.) are not yet "set in concrete". So we must consider other regulatory guidelines

LEACHING STANDARDS
(mgs/L)

	E.P. TOX Characteristic	(MEP & others) Delisting	Landban F006	(TCLP) K061
Arsenic	5.0	0.315	—	—
Barium	100.0	6.3	—	—
Cadmium	1.0	0.063	0.066	0.14
Chromium	5.0	0.315	5.2	5.2
Lead	5.0	0.315	0.51	0.24

LEACHING STANDARDS FOR ORGANICS
(mgs/L)

HW No.	Contaminant	Regulatory level
D019	Benzene	0.07
D021	Carbon Disulfide	14.4
D022	Carbon Tetrachloride	0.07

Tentative OAQPS tests for air emissions

CONCLUSION

- In general, one or more methods of immobilization will be good candidates as part of an integrated treatment process for ANY waste
- But you must match the waste to the technology & select apptopriate pretreatments

FIELD IMPLEMENTATION PROCEDURES

UTILIZED FOR S/S

SECTION 7

Abstract 7-2
Slides 7-6

FIELD IMPLEMENTATION PROCEDURES UTILIZED FOR STABILIZATION/SOLIDIFICATION

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There are usually six functions which must be satisfied for the successful implementation of a stabilization/solidification project. They are:

- Waste removal
- Untreated waste transportation
- Chemical reagent storage
- Waste/reagent mixing
- Stabilized/solidified waste transportation
- Stabilized/solidified waste replacement

In addition, waste may have to be stockpiled, moved or further processed in pretreatment operations such as dewatering or neutralization. Some processes may not require all of the steps, such as in-situ stabilization/solidification where the reagent is brought to the waste and it is stabilized/solidified in place.

Waste Removal

Due to the large quantities of waste which are usually stabilized/solidified, waste removal has generally been accomplished by the use of traditional earth-moving equipment. This equipment includes tracked backhoes, draglines, bulldozers and front-end loaders. This equipment has been in use for many years in the construction industry. Thus, its application to hazardous waste use is merely one of adaptation. The physical state of the waste may indicate the sequencing of operations necessary for the site. For example, the presence of a liquid above the waste can be managed by removal of this supernatant and treatment as a separate waste. The safety aspects of the waste relate to the equipment operators and other workers. Complete enclosure of the operator space in construction equipment and the provision of breathing air may be necessary.

Tracked backhoes and draglines are used for the remote removal of materials. Typically a backhoe is used in cases where use of equipment in an area is prevented for reasons of soil stability. Backhoe operations can occur in hazardous waste sludges which ordinarily would not support equipment. The rate at which waste is removed needs to be assessed in order that rates of material removal and transportation be as evenly matched as possible.

Draglines have application where reaches longer than 40 feet are necessary. They are delivered to a site in pieces, usually by truck, and assembled. This delivery and assembly needs to be taken into consideration as they can consume many days' time. Draglines cannot provide removals more accurately than a couple of feet. Thus, excess material is usually removed during dragline operation.

Bulldozers and front-end loaders maneuver in and on the material which is being removed. The bulldozer pushes the material by scraping. In a stabilization/solidification operation, this movement of material may be to an area where it is stabilized/solidified or to where it is loaded. Front-end loaders are capable of removal and loading of solid material. This is an advantage where the material must be placed in a dumptruck or a hopper for transportation or processing.

Waste Transportation

Depending upon the nature of the waste and of the site, waste can be transported by dump truck, pump and hose, or a fixed system such a conveyor belt or screw auger system. Dump trucks are commonly used for solids transportation, particularly when the liquid content is low and travel distance is over a quarter-mile. An important consideration is that of spillage, particularly since the waste may be hazardous. Truck beds should be lined with plastic to prevent escape of waste when the waste contains liquid or when the trucks will travel off site. In addition, the trucks should be covered with tarpaulins. Such covering is essential when the material is of a small particle size and subject to wind dispersion.

Conveyor transportation is used at a site where large amounts of waste are to be moved over a fixed distance for long periods of time. Their setup is complicated and costly, but this is offset by their ease of use once set up. Conveyors are incapable of moving liquids and spillage is a problem unless the material to be stabilized/solidified is dewatered or its water is decanted. Since a conveyor is a piece of moving equipment, time must be allotted for maintenance and repair. The use of sidewalls may be necessary to prevent unwanted dispersal of hazardous materials.

Pumping of hazardous waste solids may be feasible when they are sludge-like. In this instance the transportation function is also the removal function. Pumping has the advantage that the waste can be directly sent to the processing equipment.

Chemical Reagent Storage

Material stockpiling is an obvious requirement for the satisfactory operation of a stabilization/solidification process. Primary requirements are: (1) sufficient storage of agent so that operations are not delayed; (2) ability to keep the agent dry, since virtually all stabilization/solidification agents are dry; and, (3) ease of unloading upon delivery from the supplier and to the process. Bins and hoppers are the primary storage vessels for solid agents. These hoppers are sometimes transportable. Liquid storage is occasionally required. Sometimes solid materials are delivered to the site in bags, which are palletted, or in bulk for storage in piles. Typical chemical storage tanks are routinely used for this function.

Waste/Reagent Mixing

Mixing of the hazardous waste and its stabilization/solidification agent is the heart of the stabilization/solidification process. Most of the stabilization/solidification activities that have occurred in the United States have used area mixing. In area mixing, the waste is usually neither removed nor transported prior to the addition of a stabilization/ solidification agent. Instead, the stabilization/solidification agent is delivered to the area to be stabilized/solidified and mixed with the waste directly. Often, tracked backhoes are used for mixing. Typically, the water has enough waste present for reaction with the stabilizer/solidifier and the waste. The waste is mixed until the operator perceives that mixing is complete. The benefits to this type of mixing are: (1) the waste usually need not be removed from the site; (2) the operation can proceed with traditional earth moving equipment; and (3) it is inexpensive. Offsetting these benefits is the probable incomplete and inadequate mixing of the waste.

A wide range mixing equipment exists for use in industries which process solids. Typical mixing equipment, suitable for use in stabilization/ solidification operations, are as follows: pug mills, ribbon blenders, mueller mixers, extruders, screw conveyors. Waste and reagent can be metered into this equipment upon mixing as a means of quality control.

Some waste stabilization/solidification contractors report the use of pug mills for mixing operations. Pug mills are manufactured by several companies; contractors occasionally modify the pug mill to suit their special needs. Pug mills consist of double screws into which one material is mixed with another on a flow-through basis. The materials are generally mixed prior to their addition to the pug mill, but this is only partial mixing.

The placement of soil-like materials can be performed in accordance with procedures used in the roadbuilding industry. Here, the stabilized/solidified waste is placed in lifts of eight to ten inches using earth-moving equipment such as graders or bulldozers. Following placement, the waste is compacted. To assure proper compaction, the optimum moisture content of the material needs to be determined. The optimum moisture content is that moisture which gives the greatest density for a given material. The addition of moisture is necessary because too little moisture does not provide the required lubrication for the soil particles to slide past one another during compaction. Too much moisture causes the material to approach the density of water, which is presumably lower than that of the waste. Thus, for soil-like stabilized/solidified hazardous waste, the amount of water in the waste must be controlled as the waste is compacted.

A second factor which affects the compaction of the waste is the particle size distribution of the material. Poorly graded wastes, which are predominantly of one particle size only, do not compact well. Well-graded materials compact better since the void volume of the larger particles is occupied by smaller particles giving a better fit. This consideration is usually one that cannot be controlled unless the particle size distribution of the stabilization/solidification agent can be regulated.

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GENERAL PERSPECTIVES

- Highly site-specific
- Dependent on other project phases
- Expanded QA/QC program

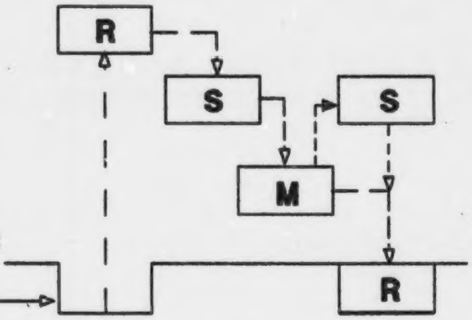
PROJECT DEVELOPMENT

• Site/waste characterization	Define problem(s)
• Technology screening	Identify solution & formulate implementation approach
• Treatability testing	Demonstrate technical feasibility for a practical implementation scheme
• Pilot testing/design	Develop/specify tailored remedy

→ **IMPLEMENTATION**

BASIC IMPLEMENTATION FUNCTIONS

- Pretreatment
- Removal
- Storage
- Mixing
- Replacement



GENERAL PREPARATIONS

- Access
- Site preparation - utilities
    - grading for roads
    - security
- Health & safety - protective clothing
    - monitoring equipment
    - dust control
    - emergency medical
    - communications
- Decontamination - non-expendable equipment
    - workers
    - collection/treatment of rinseates

PRETREATMENT

- Removal of large objects
- Dewatering - water table suppression
    - drainage beds
- Neutralization - safety
    - protection of equipment
    - as part of treatment
- Initial homogenization

WASTE REMOVAL

- Operation in waste
    - bulldozers scrape waste
    - front-end loaders move and load waste; they can be tracked or use low pressure tires
- Remote operation
    - backhoes
    - draglines
- Consider equipment reach, cycle time (make certain enough truck/conveyor capacity is present to haul waste)

TRANSPORTATION

- Pump & hose to remove liquids
- Dump truck
    - line & cover
    - decontamination necessary
- Conveyor belt
    - not for liquids
    - sidewalls necessary
- Screw auger

UNTREATED WASTE STORAGE

- Sloped to collect liquids
- Lined to keep base clean
- Rocks, twigs, etc. removed to avoid liner puncture
- Drainage pipes, sump & water treatment system necessary to handle liquids
- Covered to prevent waste dispersion
- Bermed to retard waste slumping
- Rubber tire loader to move waste

CHEMICAL REAGENT STORAGE

- Tank for liquids
- Solids storage
    - bins & hoppers
    - palleted bags for lime & cement
    - storage piles
- Requirements
    - keep solid reagents dry
    - ease of unloading is important
    - have sufficient quantity of reagent on-hand to prevent delays in operation

WASTE/REAGENT MIXING

- Mobile plant
- Area
- In situ
- In drum

MOBILE PLANT WASTE/REAGENT MIXING

- Pug mills, ribbon blenders, mueller mixers
- Process control (QC) is good
- S/S waste replacement
  - place in lifts of 6" to 8"
  - compact considering optimum moisture content & particle size

AREA WASTE/REAGENT MIXING

- Uses traditional earth moving equipment
- Technique
  - use LPTs or wide tracks if in waste
  - use timber matts to support backhoes
- Lime stabilization techniques
  - soil preparation
  - lime spreading
  - soil/lime mixing
  - compaction to achieve practical density
  - curing

AREA WASTE/REAGENT MIXING
(Continued)

- Advantages
  - inexpensive
  - waste stays on site (no transportation & disposal costs)
- However, mixing may be poor

IN-SITU MIXING PROCESSES

- Used largely for pits, ponds, lagoons, where liquids & sludges are present
- Vendors
  - Geo-Con
  - Enreco
  - Harmon
  - others

GEO-CON PROCESS

- S/S agent delivered by auger & caisson into waste
- Mixing done by lifting & turning action
- Depths to 100 ft. can be stabilized
- Overlapping bore patterns allow for complete coverage
- Advantages
  - waste not excavated
  - water table not lowered
  - fugitive emissions controlled
  - feed of agent can be metered for good QC

GEO-CON PROCESS
Continued

- Cannot penetrate masses with boulders or debris
- Has other geotechnical applications
  - dams
  - slurry walls
- SITE Program demonstration project

ENRECO IN-SITU PROCESSES

- S/S agent fed through injector on backhoe
- Mixing done by back & forth action of delivery head
- Depths to 100 ft can be stabilized
- Volume increases of 10% can be expected

HARMON

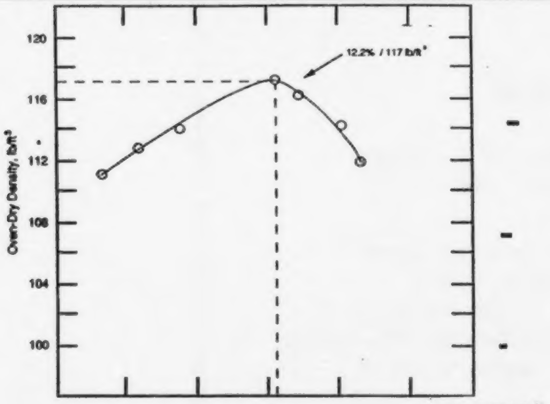
- HSS system
  - auger on front end of bulldozer
  - good for 8" to 10" lifts
- PF-5 injector
  - 5 injection tubes have impellers & augers to promote mixing
  - these tubes are at the end of a backhoe which reaches into the waste
  - can be used to depths of 10 ft

IN-DRUM WASTE/REAGENT MIXING

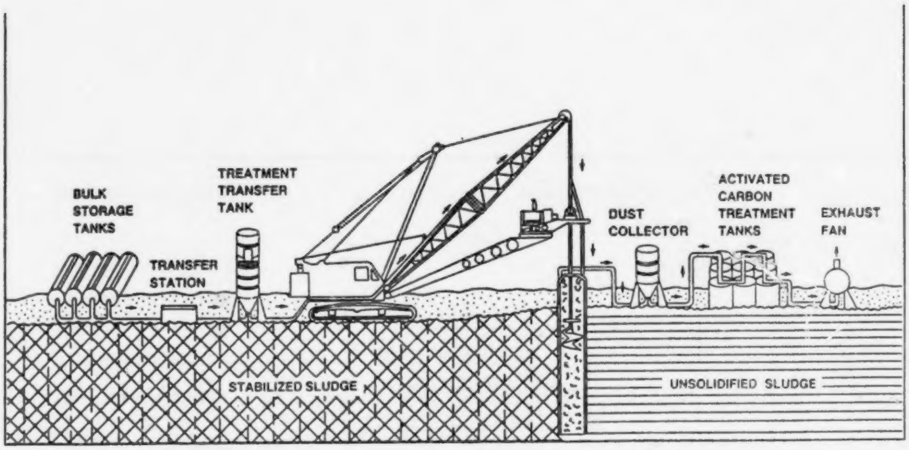
- Use drum as mixing vessel & waste container
- Reagent will require additional volume (more drums)
- Important considerations
  - how to access drum (bung hole, top removal)
  - safe operation?
- Required equipment
  - onsite chemical storage
  - chemical batching system
  - mixing system
  - drum handling system

REPLACEMENT

- Pumpable product
  - fluid or "concrete like"
  - time
  - vibration to remove air voids
- Compactable product
  - cohesive or friable "soil-like"
  - moisture conditioning for maximum density



Typical soil-cement moisture/density relationship.


BULK
STORAGE
TANKS
TRANSFER
STATION
TREATMENT
TRANSFER
TANK
DUST
COLLECTOR
ACTIVATED
CARBON
TREATMENT
TANKS
EXHAUST
FAN
STABILIZED SLUDGE
UNSOLIDIFIED SLUDGE

Crane-mounted mixing system advancing through unstabilized/unsolidified sludge layer.

Source: Geo-Con Inc., Pittsburgh, PA.

OTHER FACTORS

- Segregation
- Thickness
- Exposed surface area
- Cover

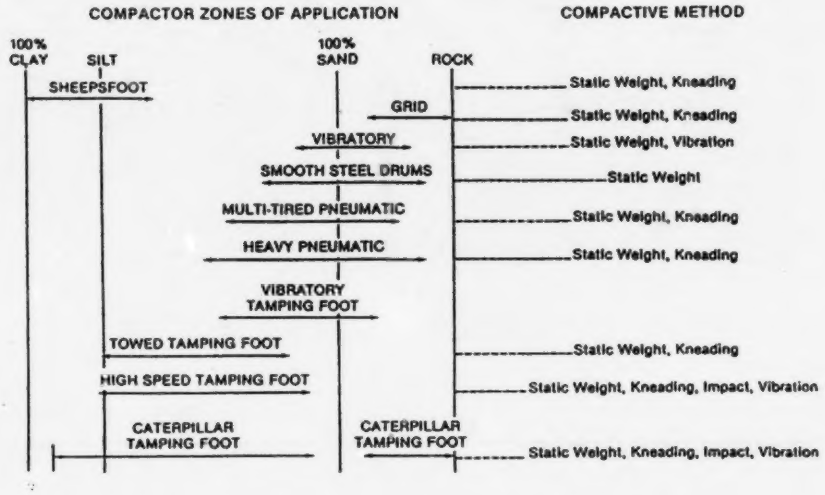

COMPACTOR ZONES OF APPLICATION
COMPACTIVE METHOD
100% CLAY
SILT
100% SAND
ROCK
SHEEPSFOOT
Static Weight, Kneading
GRID
Static Weight, Kneading
VIBRATORY
Static Weight, Vibration
SMOOTH STEEL DRUMS
Static Weight
MULTI-TIRED PNEUMATIC
Static Weight, Kneading
HEAVY PNEUMATIC
Static Weight, Kneading
VIBRATORY TAMPING FOOT
TOWED TAMPING FOOT
Static Weight, Kneading
HIGH SPEED TAMPING FOOT
Static Weight, Kneading, Impact, Vibration
CATERPILLAR TAMPING FOOT
CATERPILLAR TAMPING FOOT
Static Weight, Kneading, Impact, Vibration

Chart used to select equipment for compaction of various-sized media.

Source: Caterpillar, Inc. Caterpillar Performance Handbook, October 1987.

QUALITY ASSURANCE PROCEDURES FOR ENSURING LONG-TERM PERFORMANCE

SECTION 8

Abstract 8-2
Slides 8-5

IMPROVING QUALITY ASSURANCE/QUALITY CONTROL FOR SOLIDIFICATION/STABILIZATION

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Overview

Quality Assurance/Quality Control (QA/QC) is the backbone of all solidification/stabilization (S/S) actions involving Superfund and RCRA wastes. From waste characterization through bench testing, pilot testing and implementation of the remedy, a through and well managed QA/QC program is the only means by which confidence in the finished product can be estimated.

Quality Assurance is defined as all activities designed to ensure that a specified product performance will be achieved with a stated level of confidence. Quality Control is a part of QA and involves all activities intended to control the quality of a product so that it does meet the specified criteria. Whereas QA relates to planning and overall verification (what and how), a QC program involves checks on the measurement systems to demonstrate that they are in calibration and being applied properly at the right time and place. A simplification of the concept might be stated as: "QA IS DOING THE RIGHT THING; QC IS DOING THINGS RIGHT."

Treatments of this subject often tend to focus on QA/QC objectives (accuracy, precision, etc.) and can be less than enlightening since statements describing the level of numerical control anticipated or desired do not help to answer the questions "What should I measure and how?" "How good is good enough and how will I know when I've succeeded?" The usual answer to the latter question is "good statistics", but good judgement and common sense are at least as important. Cookbook methods do not exist and cannot be offered here. What can be offered are suggestions based on limited experience that may help to minimize oversight, avoid latent pitfalls and in general improve our ability to generate reliable information.

A sound engineering strategy and a good understanding of the relationship between project phases is key to making appropriate decisions along the way. Each phase of the project builds upon the observations and findings of the proceeding phase; for better or worse. For practical reasons, however, this dicussion focuses on specific problem areas in specific phases of a typical project. For example, although the topic of mixing is relevant in several phases, it is discussed in connection with pilot testing since this phase represents the "bridge" between idealized bench testing and the real conditions to be encountered in implementation. A general outline of this session follows:

Site Conditions

- Characterization and Sampling Practice for Known and Unknown Conditions

Bench Testing

- Physical Sample Size and "Representativeness"
- Chemical Baseline Needs
- Significant Variability in Analytical Data and other Factors affecting Test Results

Pilot Testing

- Mixing Practice, Parameters and Performance

Implementation

- Process Control Requirements and suggested methods for Monitoring Uniformity
- Prescriptive versus Performance Contracts and Impacts on QA/QC

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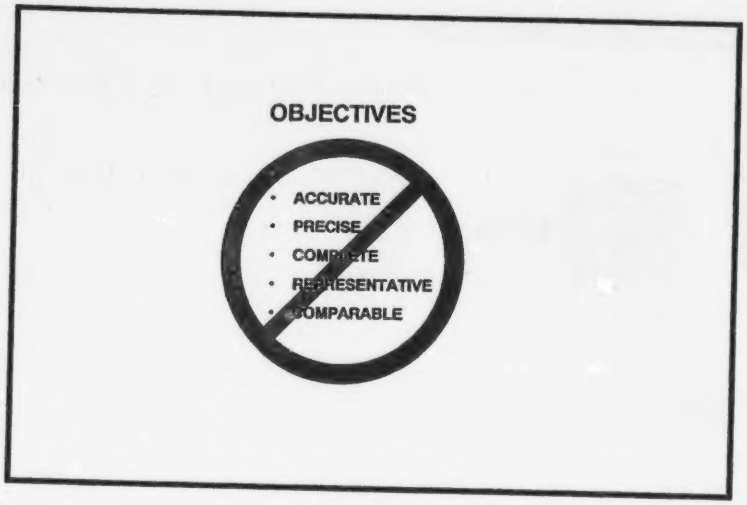
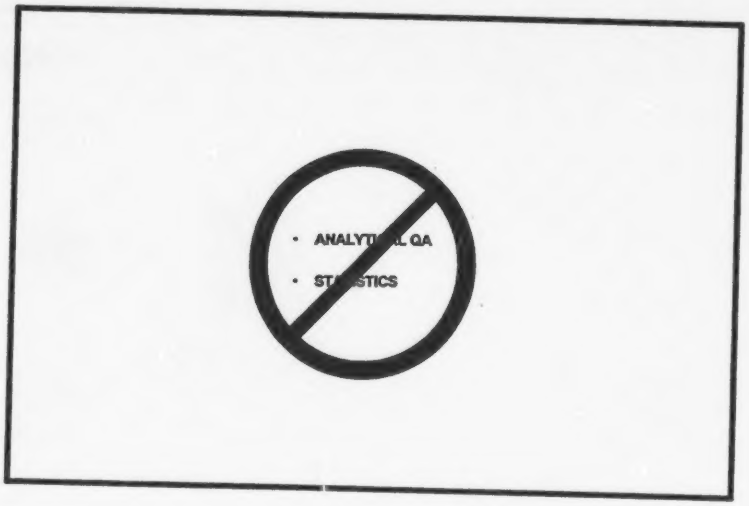
Soil Sampling Quality Assurance User's Guide; Second Edition, EPA/600/8-89/046, March, 1989.

Taylor, John Keenan, Quality Assurance of Chemical Measurements; Lewis Publishers, Inc., Chelsea, Michigan, 1987.



OBJECTIVES

- ACCURATE
- PRECISE
- COMPLETE
- REPRESENTATIVE
- COMPARABLE

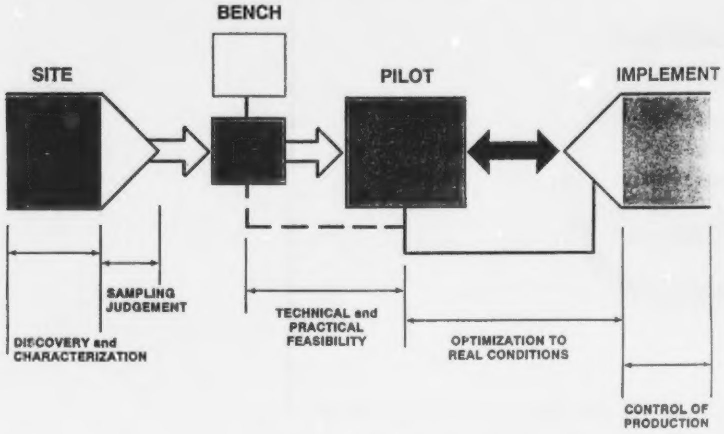


- ANALYTICAL QA
- STATISTICS

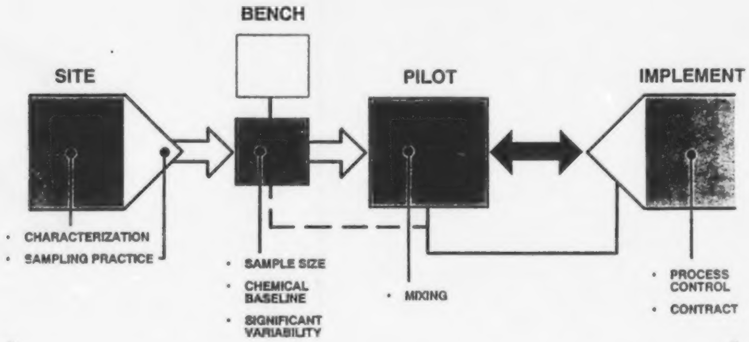
QA: DOING THE RIGHT THING
(what)

QC: DOING THINGS RIGHT
(how)

PHASED ENGINEERING APPROACH


BENCH
SITE
PILOT
IMPLEMENT
SAMPLING JUDGEMENT
DISCOVERY and CHARACTERIZATION
TECHNICAL and PRACTICAL FEASIBILITY
OPTIMIZATION TO REAL CONDITIONS
CONTROL OF PRODUCTION

TOPICS for REVIEW


BENCH
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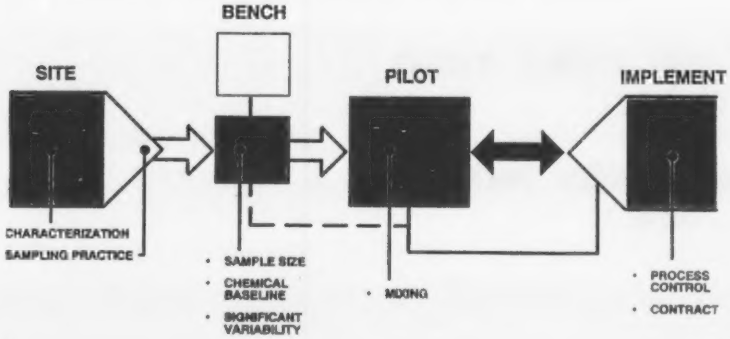
IMPLEMENT
• CHARACTERIZATION
• SAMPLING PRACTICE
• SAMPLE SIZE
• CHEMICAL BASELINE
• SIGNIFICANT VARIABILITY
• MIXING
• PROCESS CONTROL
• CONTRACT

TOPICS for REVIEW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CHARACTERIZATION AND SAMPLING PRACTICE

Critical Information

- Waste types
- Conditions
- Distribution
- Quantities

CHARACTERIZATION AND SAMPLING PRACTICE

Sampling Design

- "ASTM Standard Guide for General Planning of Waste Sampling" (in development)
- Not for unknown or abandoned sites or wastes

CHARACTERIZATION AND SAMPLING PRACTICE

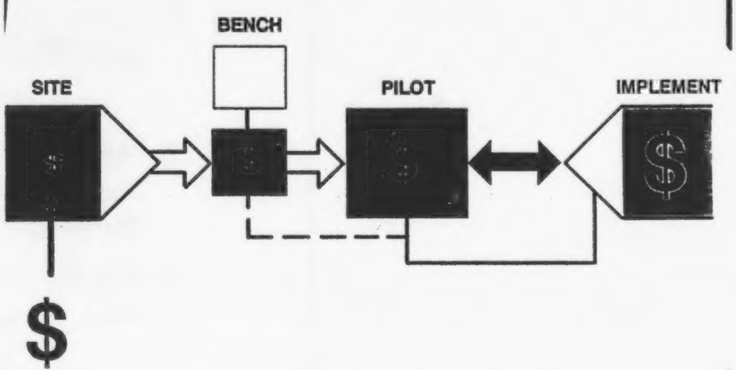
Sampling Schemes

- Judgement: deciding through visual observation or knowledge of the site
- Systematic: statistical basis for entire waste body only where known to be homogeneous; otherwise by waste stratigraphy
- "n" can be calculated based on estimate of variance of NORMAL population
- Lillefors "goodness of fit" test for normality of population generally required

CHARACTERIZATION AND SAMPLING PRACTICE

- Product
  - Credible "worst case" composite for bench testing
- Level of effort

EXPENDITURES FOR INFORMATION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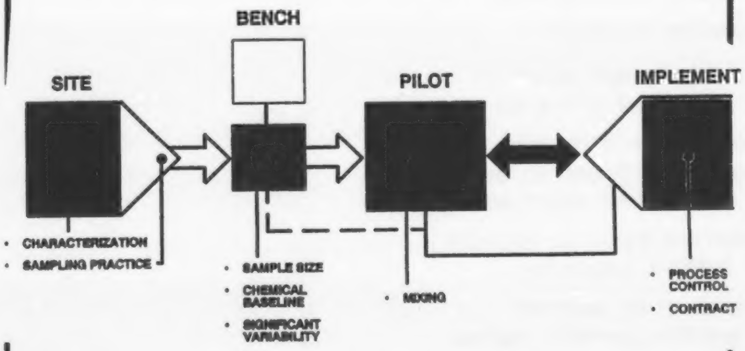
TOPICS for REVIEW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SAMPLE SIZE

- Representative physical size....not "n"
- Some guidance for physical tests (ASTM)
  - concrete specimens for strength: minimum dimension of sample = 3 times maximum dimension of largest particle
  - grain size distribution of soils: mass of sample for test "proportional" to nominal diameter of largest particle

SAMPLE SIZE
(continued)

- Some guidance for physical tests (ASTM)
  - recognize limitations of test equipment
- No guidance for chemical tests
  - acid digestion for metals limited to a few grams
  - need to test "leach test size" samples

FRACTIONATION/ACID DIGESTION FOR HEAVY METALS
("FAD"; under development)

- Combines gravimetric separation (ASTM D4371) with cold acid extraction (MSA 19-3.4)
- Untreated waste or treated waste before "set"
- Measure amount soluble in strong acid; not "total"

FRACTIONATION/ACID DIGESTION FOR HEAVY METALS

("FAD"; under development)
(continued)

- Test entire "leach test size" specimen
  - 1 L 20% nitric acid for 100g waste (S.G.=1.1)
  - agitate 7 hours, separate (settle)
  - filter and weigh "floaters" and "sinkers"
  - analyze extraction liquid

CHEMICAL BASELINE

What?	Why?
• Waste	• Safety check • Verification of "worst case" • Interference
• Binder	• Unexpected leach test results • Hazardous?
• Waste & binder mix	• Homogeneity a bad assumption • Measure actual variability for -Calculations of confidence intervals -performance comparisons

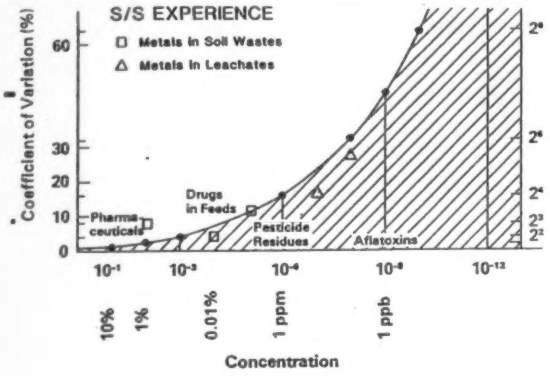
How?

SIGNIFICANT VARIABILITY

- How much variability should I expect in measuring the concentrations of analytes?
- How can I estimate variability in order to calculate "n"?

Review

CV: The variability expressed as a percentage of the mean



Interlaboratory coefficient of variation as a function of concentration.

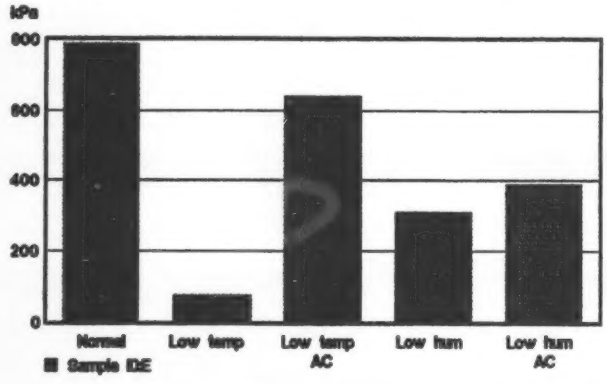
Adapted from HORWITZ ET AL: J. ASSOC. OFF. ANAL. CHEM. (VOL. 63, NO. 6, 1980)

SOURCES OF SIGNIFICANT VARIABILITY

Sample Handling

- Mixing
- Molding
- Curing
- Storage
- Shipping

UNCONFINED COMPRESSIVE STRENGTH



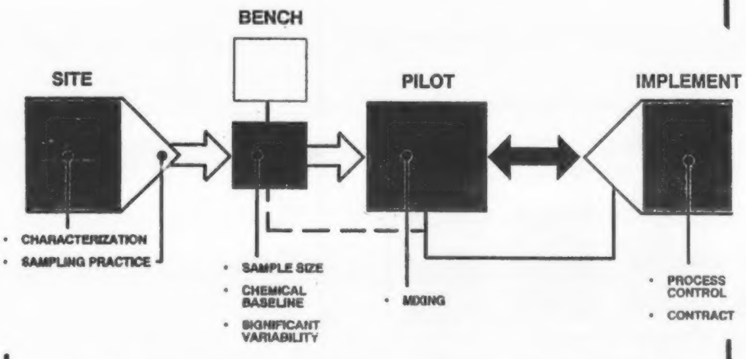
OBSERVED VARIABILITY
Replicates for Physical Testing

Test Method	# Products Tested	Median	No. of Replicates	Precision
Bulk Density (g/cc)	69	1.44	3	+/- 0.14
Specific Gravity				
Wet Method	69	2.48	4	+/- 0.28
Dry Method	55	2.34	2	+/- 0.20

OBSERVED VARIABILITY
Replicates for Physical Testing
(Continued)

Test Method	# Products Tested	Median	No. of Replicates	Precision
Moisture Content (%,w/ww)	69	25.8	3	+/- 1.6
Hydraulic Conductivity (m/s)	37	3×10^{-8}	4	630%
UCS (kPa)	66	1760	4	56%

TOPICS for REVIEW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MIXING

- Objective
  - Intimate association of waste and binder
- Practice - a materials science of three domains
  - Liquid-liquid
  - Solid-solid
  - Liquid-solid

MIXING
Bench-Scale Approach

- Small quantities
- Closest approach to ideal mixing
- May not be practical or representative of pilot scale

MIXING
Pilot-Scale Approach

- Large quantities
- Practical optimization to real conditions

MIXING

Approach to Scale-up

- Power requirement proportional to unit process volume so long as equipment geometry unchanged
- Mixing time requirement inversely proportional to mixing speed

IMPORTANT MIXING PARAMETERS

Waste and Binder

- Particle size distribution
- Bulk density
- True density
- Particle shape
- Surface area and charge characteristics

IMPORTANT MIXING PARAMETERS

Waste and binder

(continued)

- Flow characteristics
- Friability
- State of agglomeration
- Moisture content
- Density, viscosity and surface tension of liquids added

IMPORTANT MIXING PARAMETERS

Equipment

- Mechanism design - blades, baffles, cams, impellers, rollers, rods, balls, screw augers, extruders
- Intensity
- Duration/retention time - proper combination of mechanism design and intensity should produce desired blend in a few minutes; 15 minutes maximum

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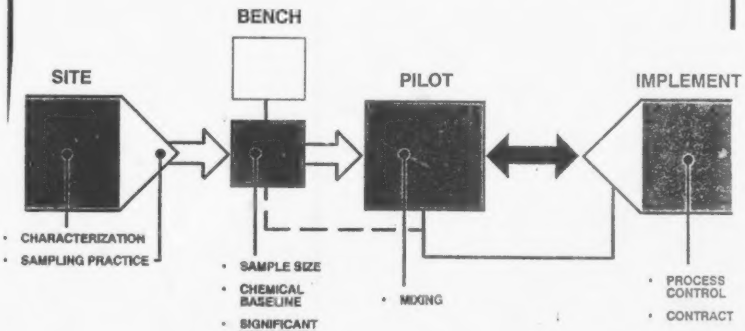
IMPORTANT MIXING PARAMETERS

Performance

- Mixing trials and evaluation required
- Refer to AIChE procedures for conducting and interpreting performance tests on mixing equipment

"Dry Solids, Paste and Dough Mixing Equipment Testing Procedure", American Institute of Chemical Engineers, Second Edition, New York, 1979

TOPICS for REVIEW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PROCESS CONTROL

- Excavation and pre-processing
- Mixing - quantities, time, energy
- Ratio control
- Documentation
- Experience

"SLOW" QC TOOLS FOR VERIFICATION ON-SITE

PHYSICAL	WASTE IN	PRODUCT OUT	TIME FACTOR
Unconfined Compressive Strength		X	D
Cone Penetrometer		X	D
Cement Content of Freshly Mixed Soil-Cement (ASTM D-2901)		X	H
CHEMICAL			
Acid Neutralization Capacity	X	X	D
Fractionation/Acid Digestion	X	X	D
Inert Spikes	X	X	D
LEACHING			
TCLP	X	X	D,M
EP Toxicity	X	X	D,M

"QUICK" QC TOOLS FOR MONITORING PROCESS UNIFORMITY

PHYSICAL INDICATORS	WASTE IN	PRODUCT OUT	TIME FACTOR
Color - Visual	X	X	M
Texture - Visual	X	X	M
Water Content	X	X	M,H
Grain Size	X	X	H
% Fines (-200 Sieve Size)	X	X	M
Unit Weight	X	X	M
Viscosity - Slump	(X)	X	M
Viscosity - Shear	(X)	X	M
Temperature	X	X	M
Optical Tracers - Dyes		X	H
Optical Tracers - Microtaggants		X	H
CHEMICAL INDICATORS			
pH	X	X	M
X-Ray Fluorescence	X	X	M

CONTRACT OPTIONS

- Prescriptive or "methods" contract
  - low contractor risk; low price
- Performance or "results" contract
  - low government risk so long as criteria clearly defined
  - higher contractor risk and cost may be offset by latitude for innovation

SUMMARY

Construction Contract Quality Management Checklist

- Waste characterization
  - Quantity
  - Condition & distribution
  - Interferants
- Treatment objectives
  - Target analytes
  - Treatment levels
  - Sampling & testing procedures
  - Required physical properties
  - Volume increase restrictions

SUMMARY

Construction Contract Quality Management Checklist

- Process Requirements

"Methods"
- Materials
- Quantities
- Proportions
- Pre-treatment requirements
- Premixing needs for processes sensitive to waste variability

"Results"
- Required physical and chemical performance
- Methods used to assess performance

SUMMARY

Construction Contract Quality Management Checklist

- Testing requirements
  - Methods for waste & binder characterization
  - Calibration of weight & volume measuring equipment
  - Mixing performance
  - Quick and simple "on-line" production tests

SUMMARY

Construction Contract Quality Management Checklist

- Post-placement tests
  - Strength, leachability
  - In situ or sampled
  - Frequency
  - Duration
  - Chain-of-custody

SUMMARY

Construction Contract Quality Management Checklist

- Contractor QC plan
  - Qualifications of technical and supervisory personnel
  - Outline of construction process with details on S/S methods, equipment & schedule
  - QC sampling & testing methods to be used
  - Action to be taken if criteria are not met
  - Health and safety

SUMMARY

Construction Contract Quality Management Checklist

- Government QA plan
  - Identify those responsible for:
    - Review/approval of contractor QC plan
    - Conduct pre-construction and periodic meetings for QM review
    - Evaluation of construction inspections and review of submittals
  - Perform:
    - Job site sampling & testing
    - Inspection of corrective actions

SUMMARY

- Invest resources to define the problem(s) as well as practical
- Establish objectives that are sensible and achievable
- Do not assume - measure
- Treat and test with implementation scheme in mind
- Calibrate indirect measurement systems used in QC
- Maintain a clear division of responsibilities in the field and document...

"If it's not written down, it didn't happen"

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